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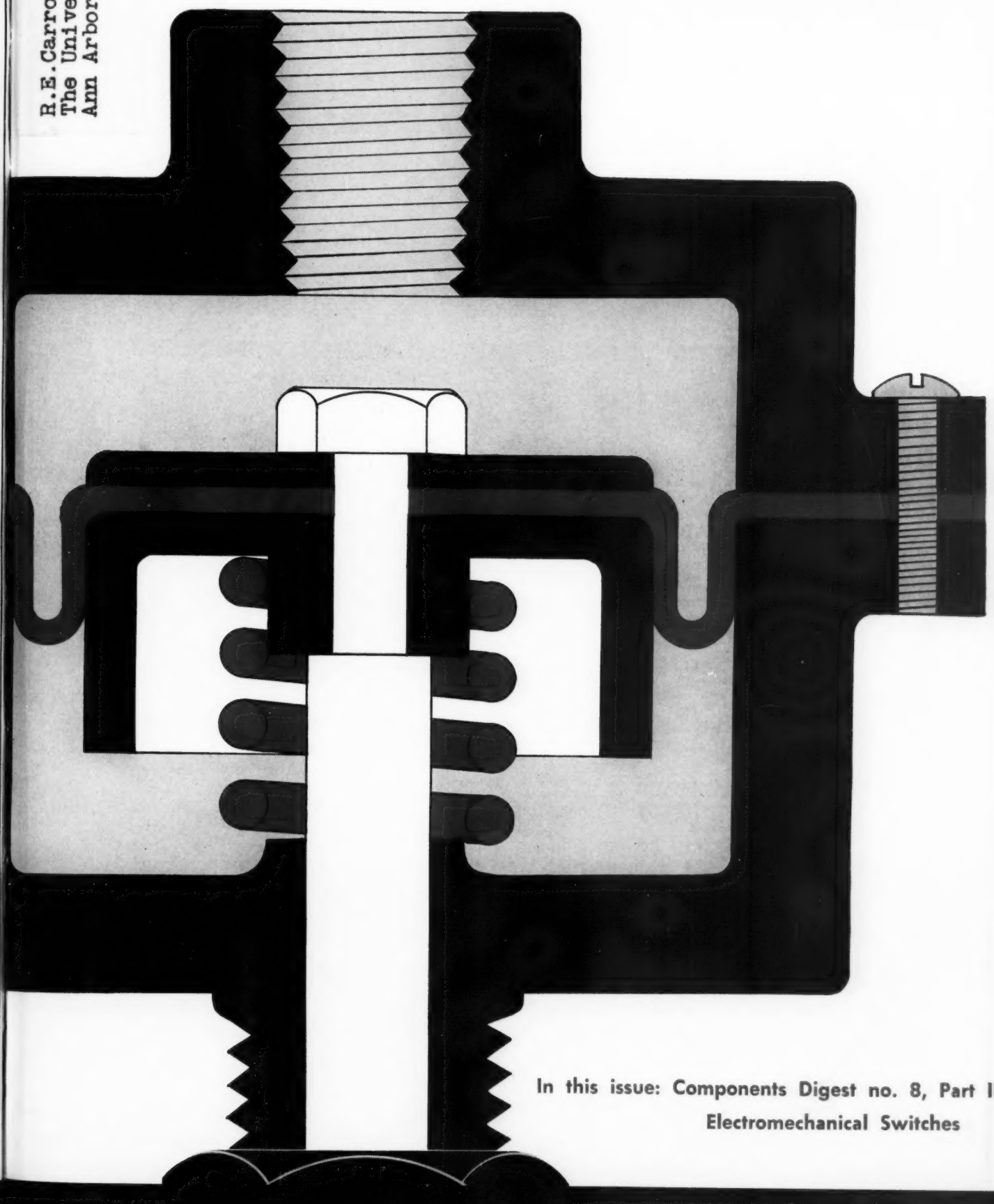
ESIGN

R.E.Carroll, Ass't.Dir.
The University of Michigan
Ann Arbor, Michigan

ELECTROMECHANICAL
components & systems | DESIGN

OCTOBER 1959



In this issue: Components Digest no. 8, Part II
Electromechanical Switches

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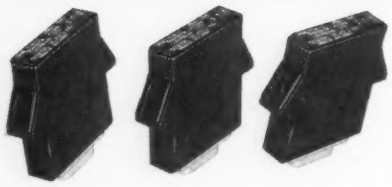

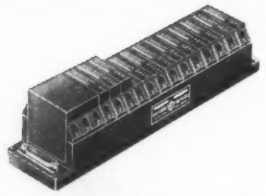

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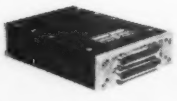

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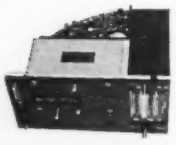

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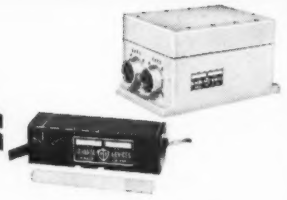

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CIRCLE 1 ON INQUIRY CARD

The Sourcebook of Design Ideas in Applied Electromechanics

VOL. 3, NO. 10

OCTOBER 1959

ELECTROMECHANICAL components & systems DESIGN

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Circulation for October: over 28,000

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CIRCLE 2 ON INQUIRY CARD

LETTERS

Pasadena, California

I am at a loss to explain to Consolidated Systems Corp., wholly owned subsidiary of CEC, why they were left out of the Buyers' Guide for Analog-Digital Converters in your August 1959 issue. Maybe you can help.

CSC is a leader in the engineering and building of data processing systems. More than 500 systems are now in service helping to acquire and process data used in a variety of purposes. Much technical knowledge and experience went into the development of the Microsadic High-Speed Analog-to-Digital Processor . . .

Roger E. Holmes, Chief
Technical Information Bureau
Consolidated Electrodynamics Corp.

To hold our Components Digest on Analog-Digital converters within practical bounds, we were forced to limit coverage to converters available as individual components, neglecting those units described as part of a system.

The Microsadic is a high speed analog-digital processing system. It continuously commutates 1 to 100 signals of sensing instruments, digitalizes them, adds to them other necessary information and records it all in a form usable by a computer at rates of up to 10,000 samples per second. It converts and preserves these signal values with greater accuracy than that with which they were initially derived (an accuracy within ± 0.1% of the true digital value). Ed

For more information on the Microsadic system, circle 220 on inquiry card.

• • • •

Philadelphia, Pa.

To say that the Components Digest articles on connectors in the May and July 1959 issues were a shock to me would be putting it ever so mildly ▸ As one of the leading manufacturers of both standard and printed circuit connectors, with the one connector in the industry that offers more in versatility and reliability than can be found anywhere else, we were humiliated to have gone through the articles mentioned and not to have found a single word about Elco's Varicon connectors.

A study such as you did can easily do us almost irreparable harm, despite the fact that our product is found in much commercial and military equipment. Why only "in your own backyard" at Raytheon and in Sylvania's "MOBIDIC" project will you find the Varicon in full use.

There has been nothing offered the Industry to date that has afforded the project, design, and packaging engineer, the versatility of design and packaging that can be found with Elco's Varicon. This in addition to a connector that has been subjected to thousands and thousands and thousands of insertion and withdrawals with no change of contact resistance!

Unfortunately, in this case, many people are swayed by what they read and those engineers who may have been "on the verge" of designing Elco's Varicon in their equipment could easily set our product aside in favor of one of the more conventional type of connectors, simply because an article like yours makes no mention of Elco and the Varicon connector . . . By the way, it was a very good article—as far as it went.

Leo Kagan
Vice President—Sales
Elco Corp.

Information on Varicons certainly did belong in our Components Digest on connectors. These Elco products employ a unique fork-like contact design that is making considerable impact on the electronics industry. Electrical contact is established by engagement of two flat tines. Four surfaces are involved in the mating action, with consequent increase in reliability over a single-point connecting device. Ability to maintain low contact resistance after repeated insertions and withdrawals is an important characteristic. Relatively low insertion and withdrawal force for a carefully assembled item is another significant factor. As Mr. Kagan says, an outstanding characteristic of this contact is its versatility. Ed

For catalog information on Elco connectors circle 221 on inquiry card.

• • • •

Cincinnati, Ohio

It has just been brought to my attention that an error exists in the summary data sheets concerning Baldwin encoders . . . The error concerns our sub-miniature encoder, Model B2.6SS13. In your summary, you have the type readout listed as parallel. The type readout should be serial. . . .

Also for purposes of discussion and for summary purposes such as the data sheet which you have provided, we feel that there could be some misunderstanding about accuracy listed as 1¼ parts in 8,192. In our bulletin #0858 we do indicate that there could be a maximum error of ±1¼ quanta. However, please note that ¼ quanta error is contributed by readout error. This does not normally concern the encoder itself, but equipment which follows . . .

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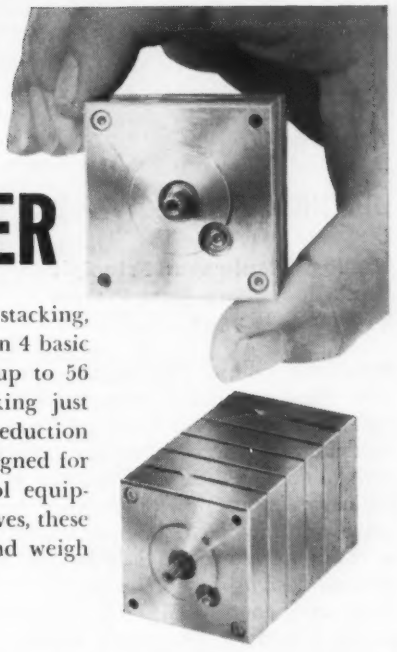

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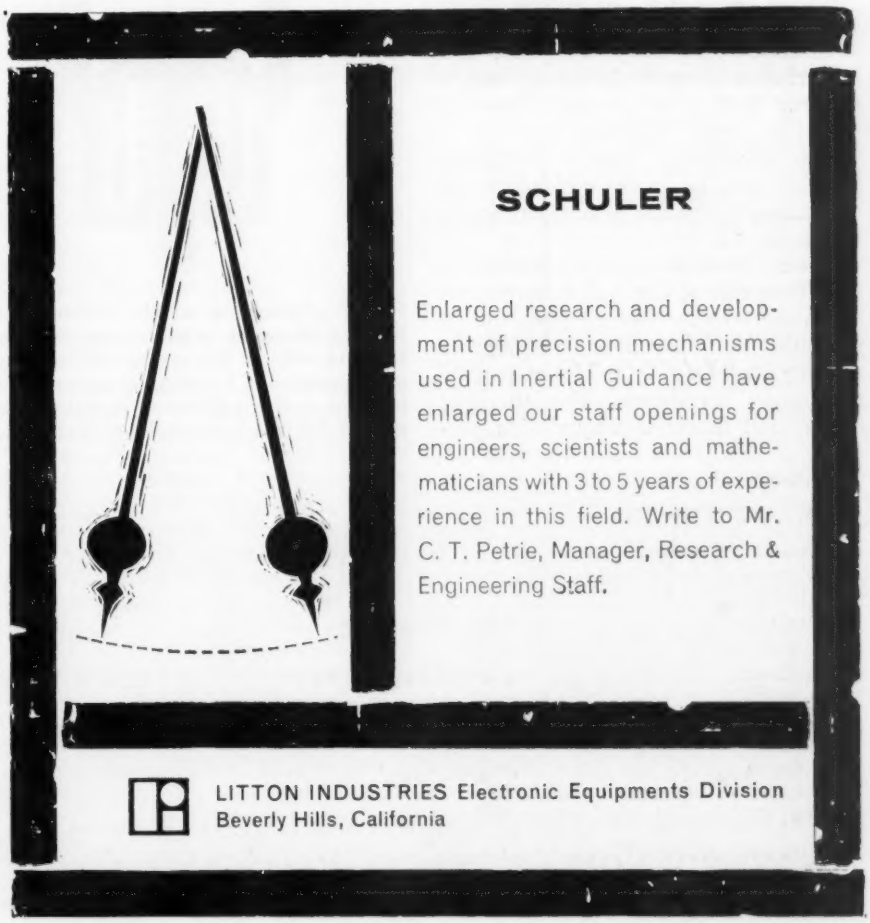

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DIAPHRAGM-BELLOWS-SEAL

Rolling Diaphragm Principle Underlies Many New Piston-Cylinder Designs

Bellofram rolling diaphragms are not new, they originated back in 1946 in the design of air-operated control mechanisms where extremely constant area and low stiffness factors were critically important. Since that time, however, they have been reappearing as the underlying principle in new and unique designs for precision measurement and control and for frictionless power functions. One such design recently announced is the timing head for a pneumatic time delay relay described in Fig. 1.

By definition a Bellofram rolling diaphragm (abbreviated–BRD) is a long stroke, deep convolution, constant area diaphragm that is free positioning with complete relaxation at any point in its stroke.

It is responsive to very small pressure changes, has no mechanical spring gradient, no break-out friction effects, possesses very low hysteresis qualities, is capable of extremely long strokes, and yet has a long flex life. It performs in many instances both a bellows and a diaphragm function, hence the term "Bellofram".

The remarkably simple Bellofram principle can be easily understood by visualizing the action of the diaphragm in Fig. 2.

The sidewall of a BRD is extremely thin. One side of the wall is supported by fabric overlay having high tensile strength, and excellent temperature stability, resulting in a highly flexible non-porous membrane. The specially constructed fabric overlay design permits elongation circumferentially, of the diaphragm, but not axially. This characteristic prevents wear from scuffing as the diaphragm rolls from the piston onto the cylinder. The fabric overlay usually is Dacron, nylon, Teflon or glass, depending on the application.

The other side of the diaphragm wall has an elastomer type synthetic rubber sealant such as, nitrile, silicone, or Viton-A, which can be compounded for compatability with practically all environmental gases or fluids. The sidewall width, including the fabric overlay and elastomer sealant generally has a thickness ranging from 0.012 inches to 0.035 inches, depending upon the materials selected for the particular rolling diaphragm application. An illustration of a typical Bellofram rolling diaphragm is shown in Fig. 3.

Fig. 3—Typical Bellofram rolling diaphragm showing fabric overlay imbedded in an elastomeric sealant material.

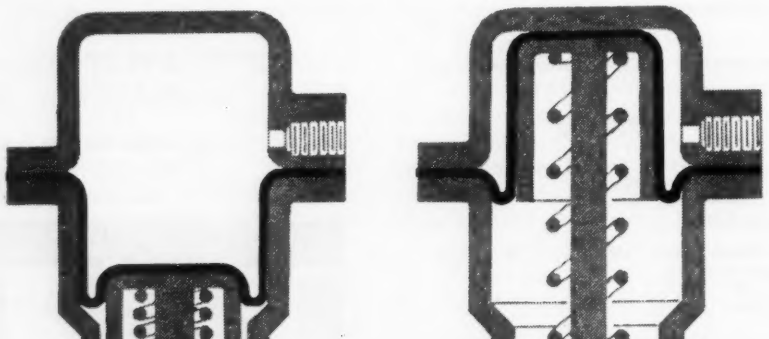


Fig. 2—Operation of the Bellofram rolling diaphragm. As the pressure in the loading chamber is increased, the piston will move downward causing the Bellofram to roll off the piston side wall and onto the cylinder side wall with a smooth and continuous frictionless action. If the pressure is released in the loading chamber the spring will move the piston upward which, in turn, causes the Bellofram to roll off the cylinder side wall onto the piston side wall.

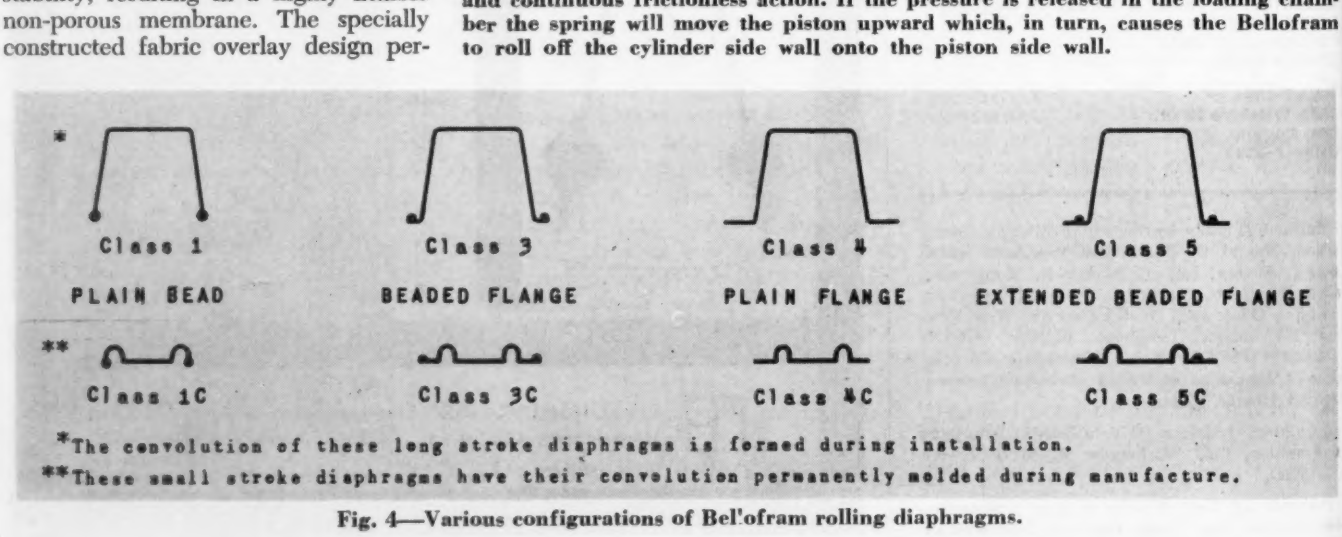
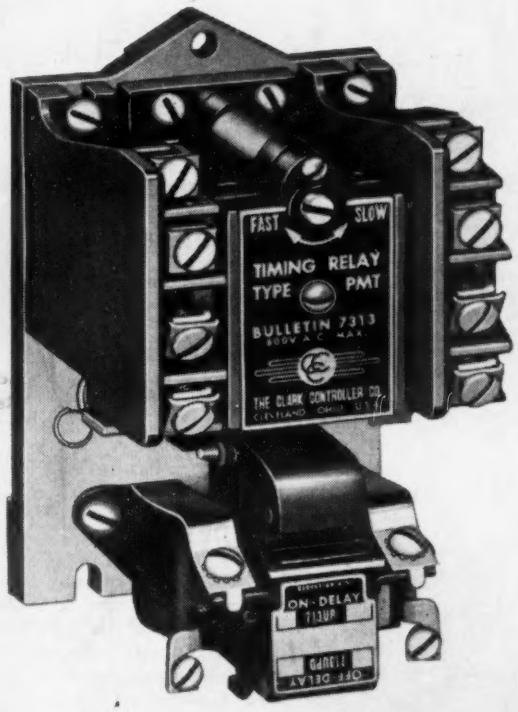
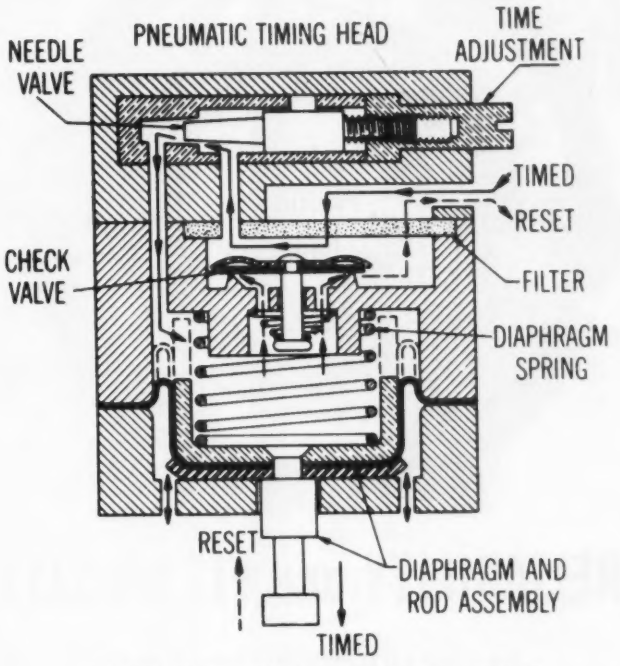


Fig. 4—Various configurations of Bellofram rolling diaphragms.





(SHOWN AT THE END OF THE TIMING STROKE)

FIGURE 1
Pneumatic time delay relay, manufactured by the Clark Controller Co., for panel board and control applications, uses the unique Bellofram rolling diaphragm principle in the timing head.

The type "PMT" pneumatic time delay relay consists of a compact timing head, a magnet and coil, and from one to four universal poles all on a mounting plate. All assembly operations, maintenance and wiring is accomplished from the front.

The pole immediately to the left of the timing head is always a timed pole, being operated from the trip lever of the timing head. The pole immediately to the right of the timing head may be either timed or instantaneous, depending on whether it is operated by the timing head, or directly from the magnet. Other poles are always instantaneous. This means that more circuits can be controlled by a single relay.

To minimize space requirements, Clark engineers mounted the timing head directly above the magnet, occupying the space of two poles so that, a two-pole time delay relay would occupy the same panel area as a four-pole "PM" relay. The problem was to design a timing head that would fit into this space, and still have the accuracy of competitive units.

The timing head uses small-diameter Bellofram rolling diaphragm with deep convolutions, riding over a piston, so the action is like a piston in a cylinder. Responsive even to small pressure changes, the diaphragm has virtually no mechanical spring gradient, and possesses extremely long stroke and flexing life. This design permits the Clark unit to displace a volume of air equal to that of competitive units, but within a smaller over-all space. The timing range provided by this device is adjustable from 0.2 seconds to 3 minutes, and repetitive accuracy is plus or minus 10%, due in part to the low hysteresis characteristics of the frictionless diaphragm.

To meet underwriters' requirements, the seal had to be designed and manufactured so that it would be flexible and resilient through temperature ranges from −30F to +200 F.

This particular relay is designed to provide "On-Delay" operation (time delay after energization) and "Off-Delay" operation (time delay after deenergization).

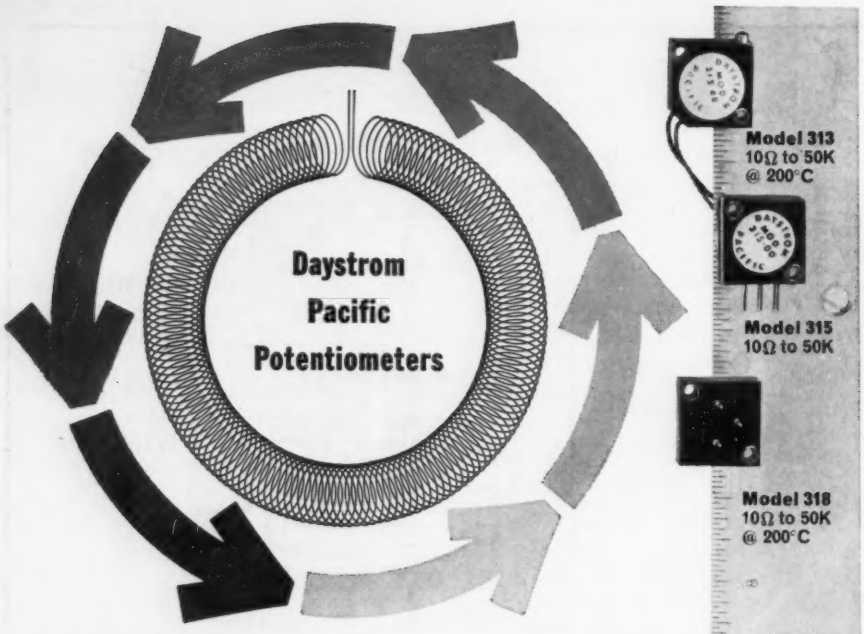
With "On-Delay" operation the magnet assembly is mounted so the armature is above the stationary magnet, and the side members of the reset spring hold the bracket and rod assembly of the magnet in the raised position while the cross-member of the spring holds up the trip lever of the timing head. The bracket, in turn, holds the timing head piston (diaphragm seal and rod assembly in the diagram) up, so the diaphragm spring is compressed, and the air is expelled from the cylinder through the check valve.

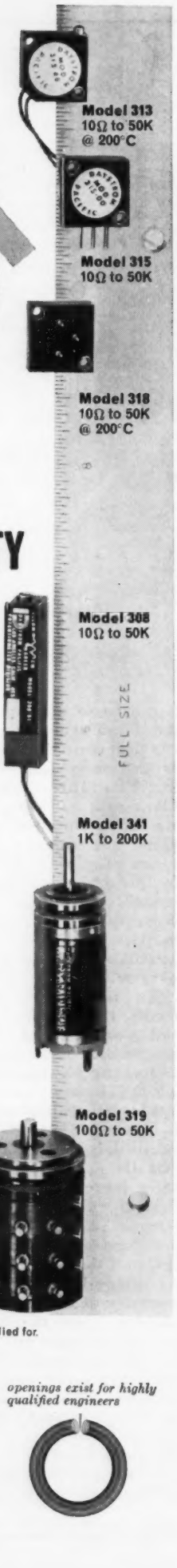
When the coil is energized, the sequence of operation is as follows: the magnet armature is pulled down, operating the instantaneous contacts immediately. In the timing head, the diaphragm spring forces the piston and diaphragm seal downward at a controlled rate, determined by the amount of air allowed to pass through the adjustable orifice of the needle valve. As the piston nears the end of its downward stroke, the piston rod trips the latch, releasing the trip lever and operating the timed contacts. When the coil is denergized, the timing head piston, timed poles, and the instantaneous poles are all reset instantaneously by the reset spring, and the relay is ready for the next operation.

With "Off-Delay" operation the magnet assembly is mounted so the armature is below the stationary magnet and with the reset spring immobilized, the upper contacts of each pole are normally closed and the lower contacts are normally opened (just opposite from the "On-Delay" condition). When the coil is energized, all poles both instantaneous and timed, are operated immediately and the timing head piston with its long stroke diaphragm is forced upward, compressing the diaphragm spring and expelling the air from the cylinder through the check valve.

When the coil is denergized, the instantaneous contacts return to the normal condition immediately, while the timed poles are delayed by the action of the timing head.

Circle 80 on Inquiry Card





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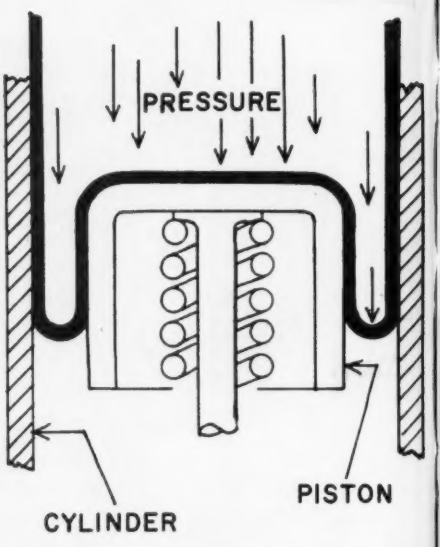

Fig. 5—In its construction, the Bellofram rol ing diaphragm consists of an elastomeric material in which are imbedded high tenacity pressure cords of modern fabric. Major part of the pressure load is supported by the central piston. The only area of the diaphragm not supported by the piston or cylinder wall is the narrow convolution, subjected to stresses which approximate only a fraction of the load-capacity of the fabric.

To clamp or attach the "BRD" to the cylinder sidewall, flanges, beads or flange-bead combinations are molded as an integral part of the diaphragm. These various combinations, identified as classes, are illustrated in Fig. 4.

Because of the unique design and patented molding procedures the Bellofram Corp., Burlington, Mass. is able to provide rolling diaphragms that are compatible with working pressures from 1 inch of water to 500 psi, and up to 1000 psi in some cases. High working pressures such as these can be applied to the "BRD" because load or force is supported by the piston head, as indicated by Fig. 5. The only portion of the "BRD" not supported is within the convolution formed by the diaphragm as it rolls from sidewall to sidewall under pressure differential. Hence the resulting force of the working pressure applied to the small convolution area is only a fraction of the total resulting force of the working pressure applied to the total effective pressure area of the piston–cylinder device.

As mentioned above, one advantage of the "BRD" is that it makes possible an extremely long stroke or travel in small diameter configurations. For example, a "BRD" of 1 inch bore is capable of providing a stroke of 1¾ inches. A 4 inch diameter "BRD" can

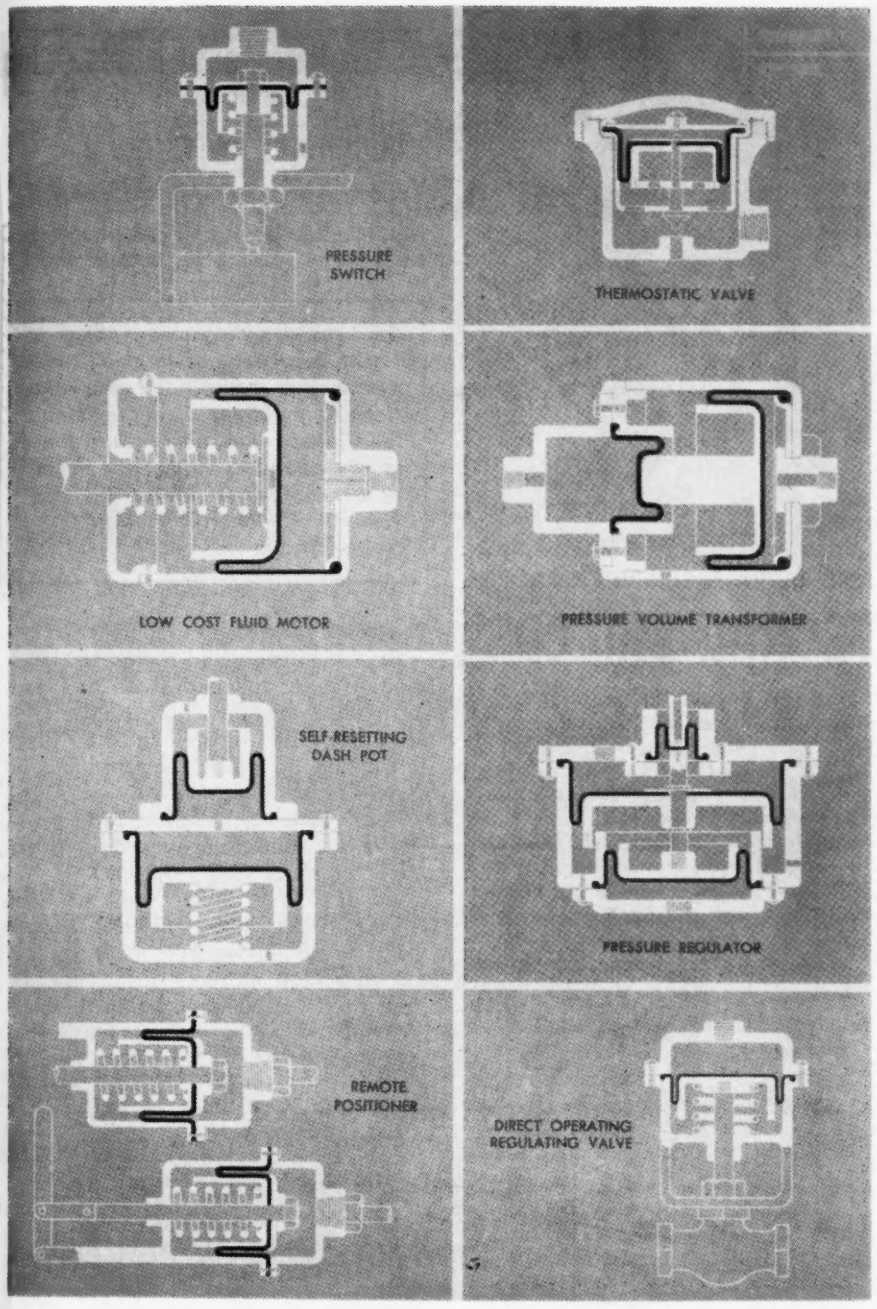

Fig. 6—Typical applications of Bellofram seals. These drawings suggest a few of the many practical applications of Bellofram seals—in such devices as regulating valves, pressure switches, remote positioners, balanced valves, snubbers, etc., in fact, in almost any piston-cylinder installation for precision measurement or frictionless power.

provide a stroke of almost 7 inches, and a 6 inch diameter bore can provide a total stroke of 10½ inches.

Because of their inherent frictionless characteristics, BRD's are often substituted for cup packings, O rings, and other conventional sealing means —particularly in cases where "breakout" friction effects cannot be tolerated.

In addition, Bellofram seals may be applied to applications involving working temperatures from −85F to +550F, and in some cases from −120F up to +700F.

Another of the inherent features is its long flex life—millions of cycles in some cases.

Finally, depending upon particular conditions, "BRD's" eliminate the need for precision machining of mating surfaces, and in many cases eliminate the need for piston guides or piston rod bearings. This simplicity in design is of great importance where cost reduction is a paramount consideration.

This new diaphragm development now provides greater design freedom for commercial and military applications in the field of pneumatic and hydraulic devices, such as are illustrated in Fig. 6.

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BASIC BUILDING BLOCKS FROM KEARFOTT

20 Second Synchro

This synchro, just one of a broad line offered by Kearfott, provides the extreme accuracy required in today's data transmission systems. Kearfott synchro resolvers enable system designers to achieve unusual accuracy without the need for 2-speed servos and elaborate electronics. By proper impedance matches, up to 64 resolver control transformers can also operate from one resolver transmitter.

TYPICAL CHARACTERISTICS	SIZE 25	
Type Resolver	Transmitter	Control Transformer
Part Number	Z5161-001	Z5151-003
Excit. Volts (Max.)	115	90
Frequency (cps)	400	400
Primary Imped.	400/80°	8500/80°
Secondary Imped.	260/80°	14000/80°
Transform. Ratio	.7826	1.278
Max. Error fr. E.Z.	20 seconds	20 seconds
Primary	Rotor	Stator

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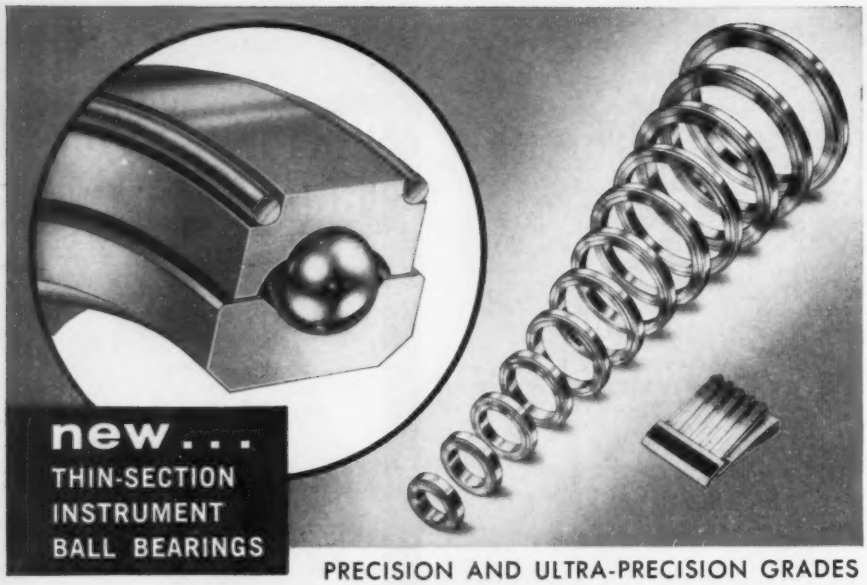
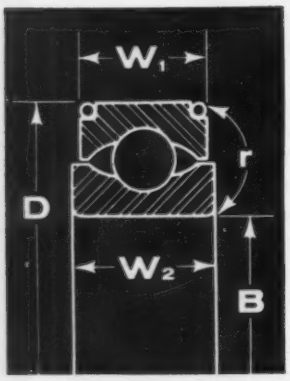


PRECISION AND ULTRA-PRECISION GRADES

TYPE TWF WITH INTEGRAL SHIELDS



A thin-section radial ball bearing with integral shields on both sides. Deep groove ball races with continuous shoulders, uninterrupted by filling slots. Maximum radial and thrust capacity possible in a radial ball bearing of its dimensions. The close-clearance annulus between shields and inner ring fills with lubricant and functions as an effective seal without the objectionable torque found with contact seals. This design in a precision instrument bearing is possible only with the Split Ballbearing method of construction. Also made in type TWA with alternate balls slightly undersize, for lower torque applications.

Balls and rings are 52100 high chrome alloy bearing steel. Also available in 440 C stainless.

number	*B bore	*D o.d.	W_1 +.000 −.005	W_2 +.000 −.005	Balls no.	Balls size	wt. lbs.	‡L lbs.	§S lbs.
TWF 10-17	.6250	1.0625	.250	.281	24	7/64	.042	276	500
TWF 12-19	.7500	1.1875	.250	.281	24	1/8	.047	354	650
TWF 14-21	.8750	1.3125	.250	.281	27	1/8	.052	375	730
TWF 17-24	1.0625	1.5000	.250	.281	32	1/8	.06	435	870
TWF 21-28	1.3125	1.7500	.250	.281	38	1/8	.07	440	1030
TWF 25-32	1.5625	2.0000	.250	.281	44	1/8	.08	470	1200
TWF 29-36	1.8125	2.2500	.250	.281	50	1/8	.09	490	1360
TWF 33-42	2.0625	2.6250	.250	.281	58	1/8	.14	520	1580
TWF 37-46	2.3125	2.8750	.250	.281	64	1/8	.16	545	1740
TWF 41-52	2.5625	3.2500	.312	.375	48	3/16	.24	1010	2900
TWF 45-56	2.8125	3.5000	.312	.375	52	3/16	.28	1040	3150
TWF 49-62	3.0625	3.8750	.312	.375	58	3/16	.32	1100	3500

Dimensions are in inches. Radius "r" will clear .015" shaft or housing fillet. *Tolerances vary according to size — see catalog 59 for Precision Grade and Ultra-Precision Grade Tolerances. ‡Radial load capacity at 500 rpm and 2500 hours average life. §Static non-brinell load capacity.

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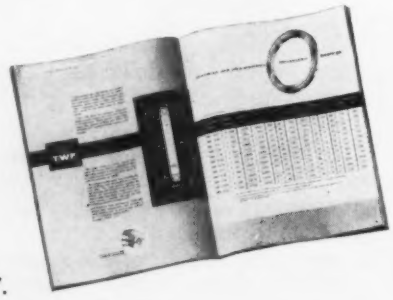

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AIR DENSITY SWITCHES

Monitoring Artificial Atmospheres In Aircraft and Missile Systems

The gas density switch, allied in function to the absolute air pressure switch, contributes new solutions to problems of arc-over and heat dissipation over wide temperature ranges. This newly developed component has served successfully in numerous military electro-mechanical systems.

Engineers designing equipment for aircraft and missiles find themselves contending more and more with problems introduced by the increasingly high altitudes, high voltages and high heat dissipation at which their product or system must operate effectively. Allied to these difficulties is the critical problem of designing to overcome increased forces of shock and vibration.

In discussing these problems, Mr. B. A. Hicks, President of Newark Controls Co., Bloomfield, N. J., points out that high altitudes mean low air pressure, or no air-pressure in the case of satellites. As a result, he says, the problem of high temperature and of electrical arc-over within electromechanical assemblies in military systems are multiplied by a large factor. A solution to both problems, he says, has been the employment of artificial environments within closed volumes. Today, according to Mr. Hicks, the most common of these "atmospheres" employ dry air, nitrogen, sulfur hexafluoride, the fluorochemicals or combination of these, each with its own characteristics, to provide insulation and heat dissipation.

But, Mr. Hicks warns, where an artificial atmosphere is to be maintained within a closed volume, gas leakage may be anticipated in such apparatus over an extended period of

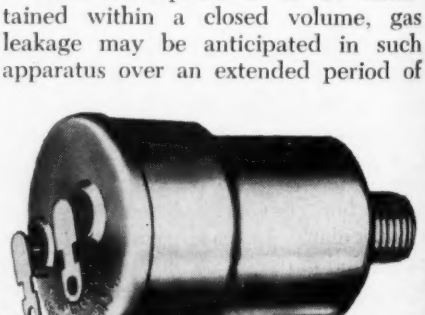


Fig. 1—The SN-88 gas density switch shown, at actual size, is in use in a variety of applications for monitoring artificial atmospheres.

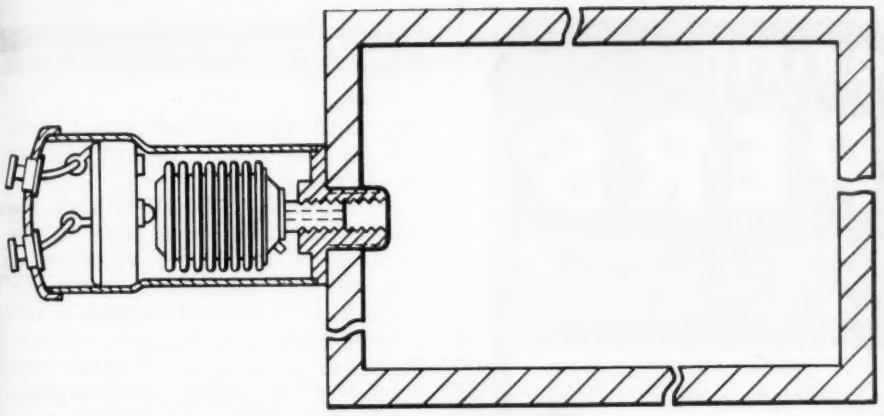


Fig. 2—Schematic drawing (not to scale) showing the gas density switch positioned externally to the enclosed assembly containing the gas to be monitored, with the pressure part inserted and sealed in the chamber. Frequently the entire swich is mountd inside the enclosed assembly.

time; some monitoring device is required to signal this leakage.

The only constant factor in the instance of gaseous artificial atmospheres in enclosed assemblies, Mr. Hicks says, is the density of the gas in terms of molecules per unit volume. Some means is required to sense, or monitor, the density of the gas with a high degree of accuracy despite variations in other conditions. That is, the monitoring device must sense the number of molecules per unit volume; it may be regarded, in such case, as sensing the weight per unit volume. The required signalling device must indicate leakage at a pressure value that varies with temperature.

An absolute air pressure switch, Mr. Hicks points out, gives an indication at the same specified pressure over the entire temperature range. Therefore it is not suited to indicating changes in quantity, or total weight, of artificial atmospheres whose pressure varies with temperatures. From this limitation, the requirement for a gas density switch evolved.

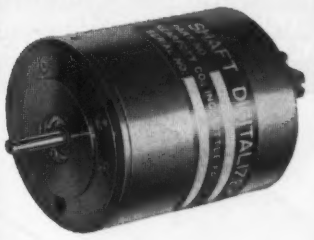
THE GAS DENSITY SWITCH

Newark Controls Company of Bloomfield, New Jersey, solved the problem of monitoring the density of gases within closed volumes with a unique bellows type switch (Figs. 1, 2). A reference density is sealed within the bellows, and the exterior of the bellows is exposed to the gas in the chamber to be monitored. The bellow's internal pressure then follows the external pressure; when the external pressure falls below the reference pressure, the switch signals this drop. In the event of leakage from the chamber the bellows extends far enough to actuate an electrical snap-action switch. The switch must be at the same temperature as the gas being sensed. Newark Controls specially designs, fabricates and tests its own electrical switch to provide the uniformity and reliability required for these applications. Such electrical switches, they say, are not generally available.

After developing the basic technique of sensing molecular densities and engineering a device that could properly react within the selected environment, Newark Controls had to solve three major problems in designing these components for airborne applications: materials to withstand temperature effects; limitations of size and weight; influence of shock and vibration.

- *Thermal effects on the structure of the unit*: The temperatures which vary the pressure also effect the materials of the switch; for example, by causing the metals to expand and contract and changing the spring constant of these materials. The selection of metals that would counteract or equalize such effects was a major design problem. Depending upon the temperature range of operation, these materials are selected from the copper base, stainless steel, or heat resisting nickel alloys.
- *Size and Weight limitations*: Available space and allowable weight in airborne applications are rigidly limited. Newark Controls has succeeded in producing units which weigh two (2) ounces, are 2-1/32″ in length and 1-5/32″ in diameter. Other specifications are that the unit be hermetically sealed and that insulation resistance be a minimum of 10,000 megohms at 500 VDC. The electrical rating is 5 amps at 28 VDC, 110 VAC, resistive loading.
- *Shock and Vibration:* The switches must function under extreme conditions of vibration and shock in excess of those required in standard government specifications. Experience gained in producing absolute air pressure switches which withstand shock and vibration, at critical pressures as

BASIC BUILDING BLOCKS FROM KEARFOTT



Analog-to-Digital Converters

Kearfott's rugged shaft position-to-digital converters are resistant to high shock and vibration and high and low temperature environments. Ideally suited for missile applications, these converters are available for many uses, including latitude, longitude, azimuth or conventional angular shaft displacement conversion and decimal count conversion. Exclusive drum design provides large conversion capacity in smallest size. Combination counter converter assemblies for both visual and electrical readout also available.

TYPICAL CHARACTERISTICS

Kearfott Unit No.	P1241-11A
Code	Cyclic Binary
Range	0-32,768 (2^{15})
Bits per Revolution	16
Revolutions for Total Range	2,048
Volts D.C.	10.5
Current (ma.)	20
Inertia (gm. cm.^{2})	20
Unit Diameter (in.)	1 1/16
Unit Length (in.)	3
Life	10^6 Revolutions or 10^3 hours
Static Torque (in.-oz.)	2 (break) 1 (running)
Weight (oz.)	5
Maximum Speed (RPM)	600

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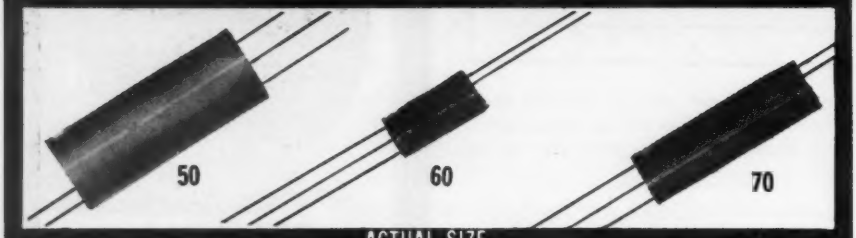


ACTUAL SIZE

Model: / Type:	50 Germanium	60 Germanium	70 Silicon
Temperature Range:	−55° C, to +85° C	−55° C to +90° C	−55° C to +130° C
Sq. Wave Drive Volt.:	1 to 10v. p-p	1 to 15 v. p-p	5 to 20 v. p-p
DC Input Voltage:	to 12 v	to 15 v	to 20 v
Chopping Freq.:	DC to 100 kcps	DC to 100 kcps	DC to 200 kcps
Alpha Cutoff Freq.:	900 kilocycles	One megacycle	5 megacycles
Temperature Drift:	.04% per °C	.02% per °C	.03% per °C
Random Noise:	25uv rms	10uv rms	50uv rms
Weight:	3 grams	1 gram	2 grams

DESCRIPTION

The transistor chopper (or modulator) is a solidly encapsuled unit designed to alternately connect and disconnect a load from a signal source. It may also be used as a demodulator to convert an a.c. signal to d.c. It is capable of linearly switching or chopping voltages over a wide dynamic range which extends down to a fraction of a millivolt and up to 10 volts. Unlike mechanical choppers which can only be designed to operate over a narrow and comparatively low frequency range due to mechanical limitations, this transistorized chopper is an inertialess device that can be driven from d.c. to hundreds of kilocycles.

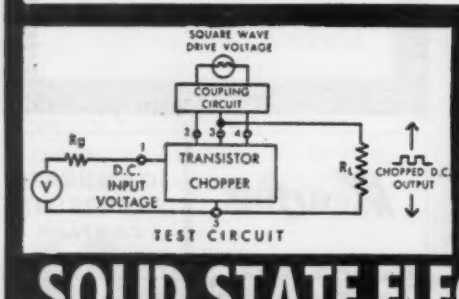
The switching circuitry used operates the transistors in a manner which provides stability and freedom from drift over a wide temperature range. Only carefully selected transistors are utilized.

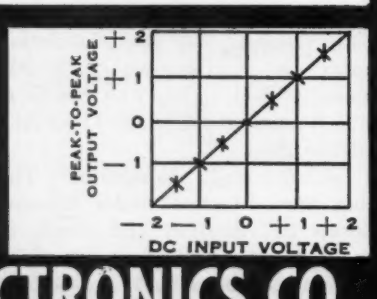
The noise figure of the transistor chopper is competitive with mechanical choppers for many uses. Furthermore, the noise level will not increase with usage.

This unit is practically immune to the effects of shock and vibration making it ideal for military, missile, and portable applications; or where power conservation, miniaturization and elimination or maintenance are a necessity. The transistor chopper has an inherently long life and is not subject to contact bounce, wear, pitting or burning.

TYPICAL APPLICATIONS

Chopper (modulator).
Demodulator.
Low, medium level switching.
D.C. amplifier stabilization.
High speed servomechanisms.
Replace less sensitive diode modulators.
Thermocouple instrumentation.
Low, medium level D.C. instruments.
Low level commutators for telemetering.
Carrier for lower frequency signals.
Digital meters.
Portable equipment.
Low power source equipment.
Minimum maintenance equipment.
Multiplex switching equipment.





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CIRCLE 8 ON INQUIRY CARD

well as at ground level, was carried over to the design of gas density switches.

In this regard, Mr. Hicks says, too little attention has been given to the problems of shock and vibration at high altitudes. He warns that many switches, both gas and thermal, which exhibit excellent performance characteristics under shock and vibration tests at sea level, do not necessarily perform satisfactorily under the critical pressures at which they will be used in airborne applications.

USES OF THE GAS DENSITY SWITCH

The sub-miniature gas density switch is in use today in a number of applications, principally in aircraft and missiles for protection of personnel and equipment. In addition to its function of signalling a critical density value, the switch may also be used to activate control circuits or systems; for example, it may open a valve or start a pump. As one example, the Boeing 707 uses a gas density switch (RM-73) to monitor the nitrogen atmosphere around the high voltages in an enclosed communication antenna coupler, where high voltages may arc-over in the rarified upper atmospheres. In some missiles employing sealed-in artificial atmospheres, the gas density switch triggers a telemetering signal back to earth if this atmosphere is lost due to leakage. Other applications include vibrating or moving machinery, power tubes, coaxial transmission lines, wave guides, x-ray equipment and packaged electronic equipment. Examples of two of the gas density switch series will illustrate their performance characteristics.

The RM-73, the first gas density switch, is designed to monitor, at

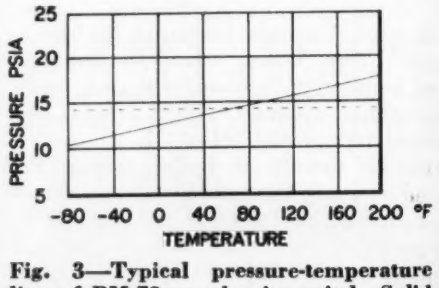
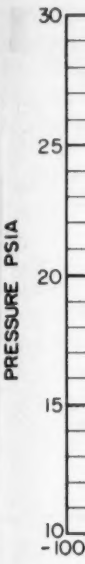


Fig. 3—Typical pressure-temperature line of RM-73 gas density switch. Solid line shows actuation pressures as they vary over the temperature range. Dotted line, by contrast, represents performance of an absolute pressure switch, which actuates at the same pressure throughout the temperature range. These switches are set to indicate a gas density or a pressure typical of those at sea level (14.7 PSI) at 75F.



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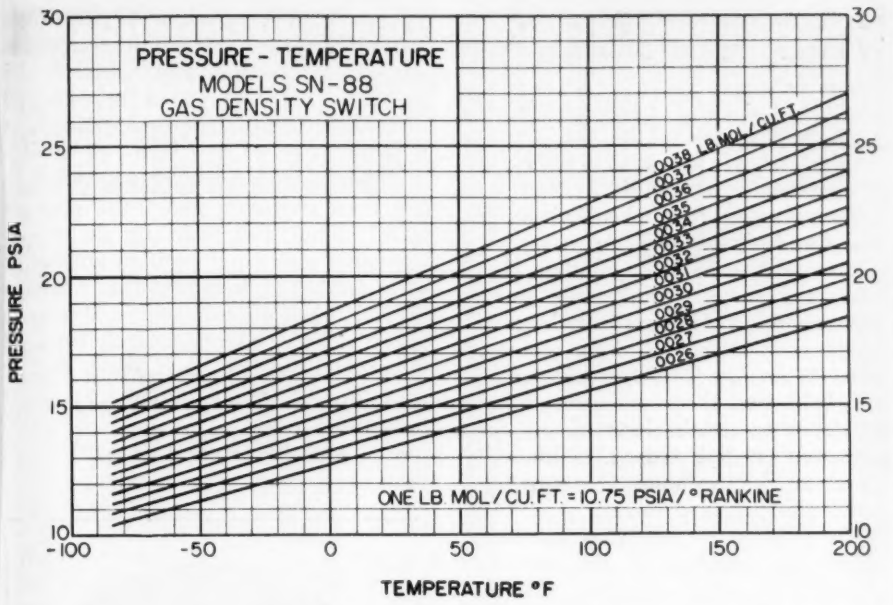

Fig. 4—The various models of the SN-88 gas density switch actuate along, or parallel to, any pressure-temperature line from .0026 to .0038 lb.-mols/cu. ft. (or from .028 to .041 PSIA/° Rankine). Specification of any two points on the required operating line is sufficient to indicate to the designer the specific actuating requirements of a desired switch.

high altitudes, concentrations typical of sea level at 75F. The typical pressure-temperature line for this switch is shown in Fig. 3. This unit is designed to operate on a pressure-temperature line the same as, or parallel to, the pressure-temperature line of .0275 PSIA/° Rankine (.0495 PSIA/° Kelvin); or on a pressure-temperature line the same as, or parallel to, the pressure-temperature line of a gas having a density of .00256 lb-mols/cu. ft. (.041 gram-mols/liter). The switches can be made to operate along the line or parallel to the line with an accuracy of ± 0.8 PSI over the temperature range −85F to +200F. Operation of the switch along a parallel line provides a safety margin in applications where this is required. The characteristics are linear through the intended operating range.

The SN-88 series of gas density switches actuate along, or parallel to, any pressure-temperature line from .028 to .041 PSIA/° Rankine or .0026 to .0038 lb-mols/cu. ft. — as shown in Figure 4. The accuracy of the actuation point for this class of switches is also ± 0.8 PSI over the temperature range −85F to +200F. The differential between the actuation and deactuation pressure is 2 PSI. This switch is employed, among other uses, to monitor atmospheres in a weapon system while in storage.

The RM-76, developed for use in the B-58 bomber, is a further development of the SN-88, the differences being its smaller size and operability at temperatures up to 400F (as opposed to 200F).

ARC-OVER AND HEAT DISSIPATION

The following comments by Mr. Hicks on use of artificial atmospheres in problems of arc-over and heat dissipation may be useful to engineers new to problems of designing equipment for high altitudes.

With the use of gas as an insulator, a potential gradient exists in the gas between two electrodes — a function of both voltage and distance. When the potential gradient exceeds a critical value, arcing occurs between the electrodes. Electrons traveling in this high electric field collide against gas molecules and cause excitation and ionization of the gas molecules. This breakdown voltage is further a function of the particular gas and its concentration (which, itself, is a resultant of pressure temperature conditions), and of the configuration and material of the electrodes. The path of the electron flow can be interrupted by a density sufficient to prevent an electron from gaining enough energy in the short distance between molecules to break up the gas molecules with which it collides. At the other extreme of very low density there are not enough molecules with which the electrons may collide, and consequently no avalanche effect occurs. As gas density is decreased from, say, that at standard temperature and pressure, the breakdown voltage decreases almost linearly for a time, reaches a minimum value and then rises again as the density is decreased further.

For many applications air and nitrogen are suitable gases as insulators and heat dissipators. However, sulfur hexa-

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Integrating Tachometers

Kearfott integrating tachometers, special types of rate generators, are almost invariably provided integrally coupled to a motor. They feature tachometer generators of high output-to-null ratio and are temperature stabilized or compensated for highest accuracy integration and rate computation. Linearity of these compact, lightweight tachometers ranges as low as .01% and is usually better than ± .1%.

TYPICAL CHARACTERISTICS

	Size 11 (R860)
Excitation Voltage (400 cps)	115
Volts at 0 rpm (RMS)	.020
Volts at 1000 rpm (RMS)	2.75
Phase shift at 3600 rpm	0°
Linearity at 0-3600 rpm	.07
Operating Temperature Range	−54° +125°

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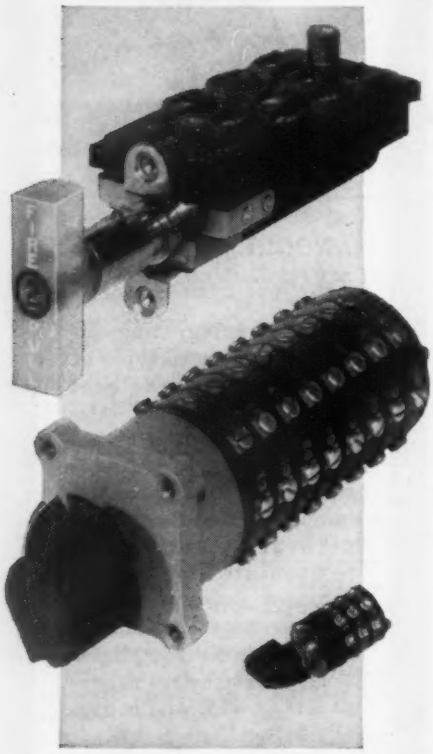
CIRCLE 9 ON INQUIRY CARD

POLLAK

Industrial
SWITCHES
Military



What do you want a switch to do?

How *you* want to use a switch is what really counts with Pollak.

Pollak makes all kinds of top quality switches from the custom-built Push-Pull, Rotary Selector, and Miniature types shown above to heavy duty switches particularly designed for use on military and industrial equipment.

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CIRCLE 10 ON INQUIRY CARD

fluoride and the fluorochemicals have superior qualities in this respect. The former liquefies at −62C at normal sea level pressure of 14.7 PSIA, the more commonly used fluorochemicals at temperatures above 50C. As gases they are superior because of their large molecular structure and other specific characteristics. The relatively large collision cross-section of these molecules extracts energy from free electrons in the field, and these molecules have a tendency to attach electrons and form impotent negative ions. Like other gases at higher density, their large molecules act as a screen.

In addition to insulating characteristics, the selection of the gas used depends on other qualities. The producers of these gases have considerable information available on their use as insulators and heat dissipators. The gas must, of course, be non-explosive and non-inflammable. Further, it must not decompose under breakdown voltages or high temperatures into either toxic or corrosive chemicals.

Under continuous arcing, as with rotary switches or brushes, sulfur hexafluoride breaks down into lower valence fluorides of sulfur, and does not regain its original identity. On the other hand, the fluorochemicals characteristically recombine.

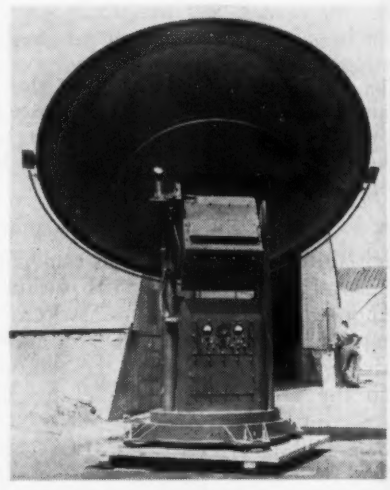
Also the temperature at which liquefaction occurs may be a factor in the selection of gas used. SF_6 remains a gas at low temperatures – the boiling point or condensation temperature being −62C at normal sea level pressure of 14.7 PSI. The fluorochemicals are normally liquid. One of the most commonly known of these is a completely fluorinated cyclic ether manufactured by Minnesota Mining and Manufacturing Co., under the name FC-75. It boils at sea level pressures at about 100C.

Circle No. 78 on Inquiry Card

Graphic Level Recorder

Transistorized, high-writing speed, 20 cps-200 kc graphic level recorder, with a variety of uses, records the rms magnitude of an ac voltage rather than the instantaneous value, and can plot the output of an ac device as a function either of time or some other parameter that can be made time dependent, such as frequency. Null-seeking servomechanism serves to position a logarithmic potentiometer and a pen to produce an ink trace on rectilinear paper. Maximum writing speed is adjustable up to 20 inches per second, which corresponds to 400 db per second permitting measurement of reverberation time as short as 0.5 second; Paper speeds: 2.5 in/min, 7.5 in/min, 25 in/min and 75 in/min, with an accessory these speeds can be reduced by a factor of 60. Input range of the device is 0 to 40 db for level recording and 0-0.8 volt (at 1000 ohms), full scale, for dc recording with zero input position adjustable over full scale. Potentiometer balances within 0.5% of full scale. Maximum sensitivity is 1 millivolt at 0 db for level recording; 0.8 volt, full scale, for dc recording. General Radio Co., West Concord, Mass.

Circle No. 144 on Inquiry Card

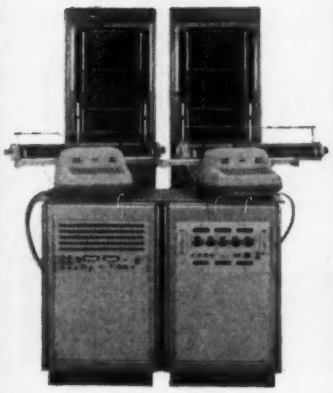


Pedestal For Scanning And Tracking Systems

New pedestal unit that incorporates advanced servo design techniques can be used in a variety of applications requiring a highly-directional, automatic or manual, tracking antenna system for the transmission and/or reception of data signals to or from distant moving airborne or surface targets. Unusual accuracy is achieved by the push-pull arrangement of clutch-type servos which provide control circuits with high natural frequencies, high accelerations, and speeds of response that are virtually instantaneous. The hystersis-effect clutches completely eliminate wear and the double gear train arrangements does away with all backlash. Specifications for the pedestal unit used in balloon tracking include: position resolution of .01° or less; 30° per minute maximum speed of automatic tracking; maximum slewing speed of 1 revolution per minute; and an acceleration of 72° per minute. Servo Corp. of America, New Hyde Park, New York.

Circle No. 203 on Inquiry Card

BASIC BUILDING BLOCKS FROM KEARFOTT

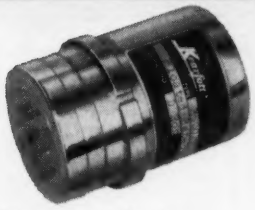


Data Logging

Kearfott's broad line of test equipment includes the Scanalog 200-Scan Alarm Logging System which monitors, logs and performs an alarm function of up to 200 separate temperature, pressure, liquid level or flow transmitters. This precise data handling system is equipped with manual controls for scanning rates, automatic or manual logging, data input relating to operator, time, day, run number and type of run. 200 numbered lights correspond to specific points being maintained and provide a visual "off normal" display for operator's warning. System can be expanded to 1024 points capacity and 2000 points per second scanning rate.

Write for complete data.

BASIC BUILDING BLOCKS FROM KEARFOTT



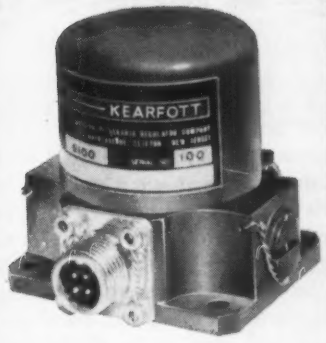
Floated Rate Integrating Gyros

Specifically designed for missile applications, these Kearfott miniature gyros operate efficiently at unlimited altitudes. Their outstanding accuracy and performance make them superior to any comparably-sized units on the market. Hermetically sealed within a thermal jacket, these gyros are ruggedly designed and completely adaptable to production methods. Performance characteristics that are even more precise can be provided within the same dimensions.

TYPICAL CHARACTERISTICS

Mass Unbalance:
Along Input Axis: 1.0°/ hr maximum untrimmed
Standard Deviation (short term):
Azimuth Position: 0.05°/hr
Vertical Position: 0.03°/hr
Drift Rate Due to Anisoelasticity
Steady Acceleration:
.015°/hr./g^2 maximum
Vibratory Acceleration:
.008°/hr./g^2 maximum
Damping:
Ratio of input angle to output angle is 0.2
Characteristic Time:
.0035 seconds or less
Weight: 0.7 lbs.
Warm-Up Time:
10 minutes from –60°F
Life: 1000 hours minimum

BASIC BUILDING BLOCKS FROM KEARFOTT



Electrohydraulic Servo Valve

Kearfott's unique approach to electrohydraulic feedback amplification design has resulted in a high-performance miniature servo valve with just two moving parts. Ideally suited to missile, aircraft and industrial applications, these anti-clogging, 2-stage, 4-way selector valves provide high frequency response and proved reliability even with highly contaminated fluids and under conditions of extreme temperature.

TYPICAL CHARACTERISTICS

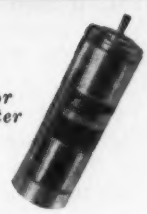
Quiescent Flow ..... 0.15 gpm
Hysteresis ... 3% of rated current
Frequency Response
3 db @ 100 cps
Supply pressure....500 to 3000 psi
Temperature-Fluid & Ambient
–65° F to +275° F
Flow Rate Range .... .3 to 10 gpm
Weight ..... 10.5 ounces

Write for complete data.

Analog Digital Converter

20 Second Synchro

Integrator Tachometer



Engineers: Kearfott offers challenging opportunities in advanced component and system development.

ON DATA LOGGING
CIRCLE 71 ON INQUIRY CARD

ON INTEGRATING GYROS
CIRCLE 72 ON INQUIRY CARD

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ON SERVO VALVES
CIRCLE 73 ON INQUIRY CARD

SPRING DRIVEN GYRO

Missile Roll Reference for $150

In design and development of a gyro for roll stabilization of a short-time-of-flight anti-tank missile, Engineers at Waltham Precision Instrument Co. in Waltham, Mass., were faced with an imposing requirement: total cost of the missile was to be under $1000, which according to Waltham's estimates meant the gyro could not cost more than $150. The major performance requirements were: starting time to be less than one-half second, and drift about the roll axis to be less than one degree for the first minute.

To achieve these requirements within the price limitation meant searching out the simplest possible design and careful cost estimates. A total of 4-man days was spent in estimating and paring down the cost before the design proposal was finalized. Some design decisions influenced mainly by cost were described by Andrew Bayle, WPIC's Vice-president and Director of Engineering.

- A spring was chosen as the driving power for the gyro rotor. Rather than use a conventional flat coil spring which would involve expensive problems of clutching and declutching, Waltham chose a helical coil spring with bevel-gear-mesh drive from the spring to the rotor. The bevel gear attached to the spring is an inexpensive sector gear which engages a mating gear on the rotor when the spring is wound. When the spring is released, the sector gear drives the rotor gear and then continues to a position completely clear of the rotor gear. A rubber bumper absorbs the remaining spring energy.
- Power for temperature control was not available. The designers recognized therefore that the effects of temperature on performance would have to be controlled by careful choice of materials and attention to differential expansion which might result in weight shift.
- A caging mechanism was not necessary. Requirements allowed simply gathering and pinning the gimbals into caged position by hand.
- Hermetic sealing was unnecessary. Since the anti-tank missile for which the gyro was being designed would operate near ground level, a seal against effects of altitude changes was not required. A dust seal and the protection of the missile housing was considered sufficient.

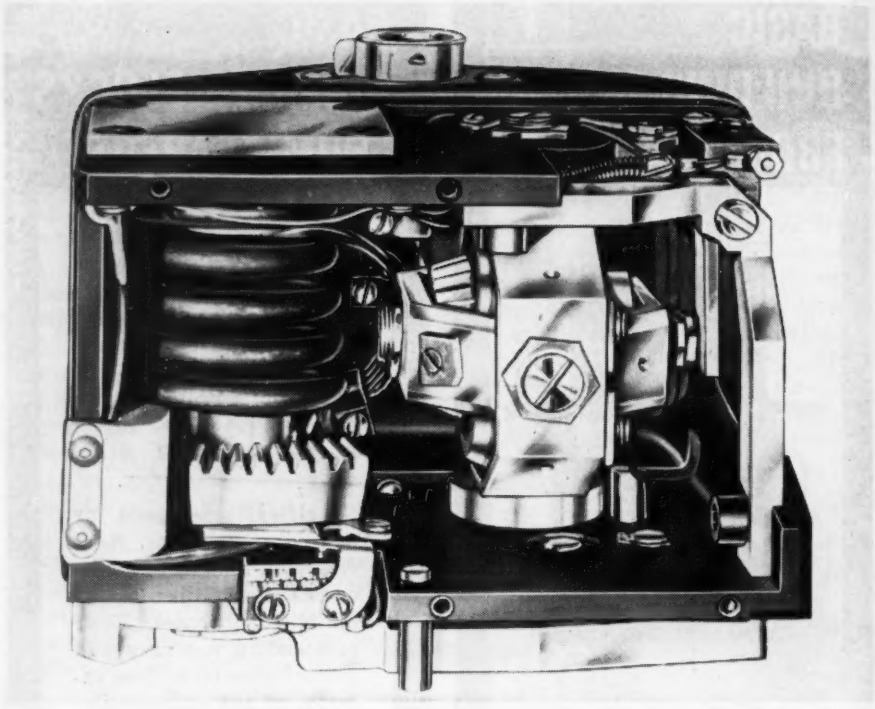


Fig. 1. Two-degree-of-freedom spring driven gyro with cover removed. The spring which provides the energy for the rotor is a helical coil spring rotated approximately 90 degrees, and held in the wound position by means of a ratchet and pawl. The pawl is released by applying a 28 volt d-c voltage to a fuse wire. The fuse wire controls a linkage which acts on the pawl by means of a small helical coil spring held in compression until the fuse blows. Spring constant of the main spring is 3.25 inch-pounds per degree. When it is fully wound the spring stores 292 inch-pounds of energy.

- Low cost fabrication techniques were required, such as slicing aluminum extrusions to make the gimbals.

OPERATING CHARACTERISTICS

The gyro is a two-degree-of-freedom instrument with the spin axis along the pitch axis of the missile, the outer gimbal axis along the roll axis, and the inner gimbal axis along the yaw axis. Since the gyro is designed for short time-of-flight, it does not need nor have an erection system. In use, the gyro is caged before take-off or launching, and the starting signal releases the spring, which energizes the rotor. When the rotor is up to speed, the gyro uncages and acts as a free gyro during flight. A potentiometer pick-off about the outer gimbal axis indicates angle of roll. During the brief time required to activate the gyro, the rotor reaches a speed of approximately 7000 RPM. It then coasts over a period of several minutes during the flight of the missile. Effective angular momentum of the gyro rotor is maintained for a period of up to three minutes after firing. For the first minute of operation, the gyro drift about the roll axis is less than one degree.

The caging system used for the gyro is extremely simple. A pin attached to the inner gimbal is constrained by a lever with a hole that fits over the pin when the gyro is caged. This arrangement effectively prevents motion of either the outer or inner gimbal. The caging lever is held in place by means of a fuse wire. When the wire blows, a small spring releases the caging lever so that it becomes disengaged from the pin. To make sure the gyro does not uncage until the sector is clear of the rotor, the uncaging fuse wire is energized through a switch actuated by the sector gear as it strikes the bumper.

The potentiometer is simply a resistance wire card attached to a cylindrical section of the outer gimbal and a wiper fixed to the frame of the gyro. Electrical connections are made to the ends of the potentiometer winding by means of pigtail wires.

DESIGN DECISIONS

In discussing the design of the gyro, Mr. Bayle emphasized several considerations peculiar to design of a spring driven gyro: size of rotor to be used, design of the rotor energizing spring, gear ratio to be used between spring and rotor, and maximizing the energy transfer between spring and rotor.

Since the size and weight of the gyro were specified, the first decision to be made was the size of the spring.

The designers allocated approximately one-half the total volume to the spring and the remainder to the rotor and gimbal assembly. A larger spring, with resulting lower-inertia rotor, would not provide sufficient gyro performance because friction and windage would limit top speed of the rotor. A smaller spring, although it would allow a larger rotor inertia, would not achieve sufficient initial speed to maintain gyro performance over the time specified.

Space available for rotor and gimbals permitted a rotor with a moment of inertia of approximately 600 gram-cm^2. The maximum-energy spring in the space available was found to be a helical coil spring with a spring constant of 3.25 inch-pounds per degree.

Theoretical considerations of gear ratio and energy transfer entered into optimization of the design. Ideally all potential energy in the wound spring would be converted into kinetic energy of the spinning rotor. In practice, energy is lost in the transfer in three principal ways:

(1) Energy required to accelerate the spring and sector gear.
(2) Energy lost in friction and windage during the acceleration period.
(3) Energy remaining in the spring after the sector gear has become disengaged from the rotor.

It is convenient to think of the spring-rotor system as a simple spring-mass rotational system, Mr. Bayle pointed out. Such a system will oscillate at a frequency determined by the spring constant and the moment of inertia of the system. Waltham, of course, was interested in something less than one quarter of one period of oscillation. Because they use a sector on the spring rather than a full gear, the system does not oscillate.

The proportion of energy required to accelerate the spring and sector gear depends on the moment of inertia of these elements, the moment of inertia of the rotor, and the gear ratio between spring and rotor. If the gear ratio is high (step-up from spring to rotor) the proportion of energy required to accelerate the spring and sector gear will be negligible. On the other hand, mechanical design considerations make it difficult to use a high gear ratio. In the Waltham gyro the ratio is 3:1, which reduces the energy loss in accelerating spring and sector gear to a second-order effect. Energy lost in friction and windage was reduced by the use of ball bearings wherever necessary.

In a practical design some energy must be left in the spring when the sector becomes disengaged from the rotor, in order that the sector will clear the rotor and gimbals, and permit freedom of motion of the gimbal system after uncaging. Analysis showed that angular velocity of the rotor is increased as the initial angle of wind-up of the sector (spring) is increased, and the angular position at release is made small. In other words, the sector angle should be as large as possible, and the spring should be wound up as far as possible.

Values of parameters chosen for the Waltham gyro are:
Spring constant: 3.25 inch-lbs per degree; rotor moment of inertia: 600 gram-cm^2; initial spring angle: 90 degrees; spring angle at release: 45 degrees, and the theoretical angular velocity of the rotor at release is 7650 RPM. In actual tests rotor angular velocity at release was measured as 7000 RPM, giving indication of the effect of energy loss in friction and windage during the acceleration period, and in accelerating spring and sector gear.

Circle No. 87 on Inquiry Card

Gravity Sensing Electrolytic Potentiometer

Three electrodes sealed in a curved glass tube partially filled with an electrolytic solution provide a unique gravity sensing unit. Electrodes are arranged so that when unit is in a horizontal position, the resistance from the two operational electrodes to the common electrode is equal. When unit is tilted, air bubble moves, causing resistance to increase on one operational electrode and decrease on the other. If the EP 1012 is used as one-half of a bridge circuit in a 1000 Ohm bridge, with 12 V. applied, zero output results at the horizontal position. Tilting the unit ¼ degree, 4 V. of the output results and at ½ degree, 8 V. Designed to give an error signal with a small amount of deviation from the horizontal, unit reaches saturation at approximately ¾ degrees. The unit is 1¾" long, including leads, and 9/32" in diameter across body.
Hamlin Inc., Evanston, Ill.

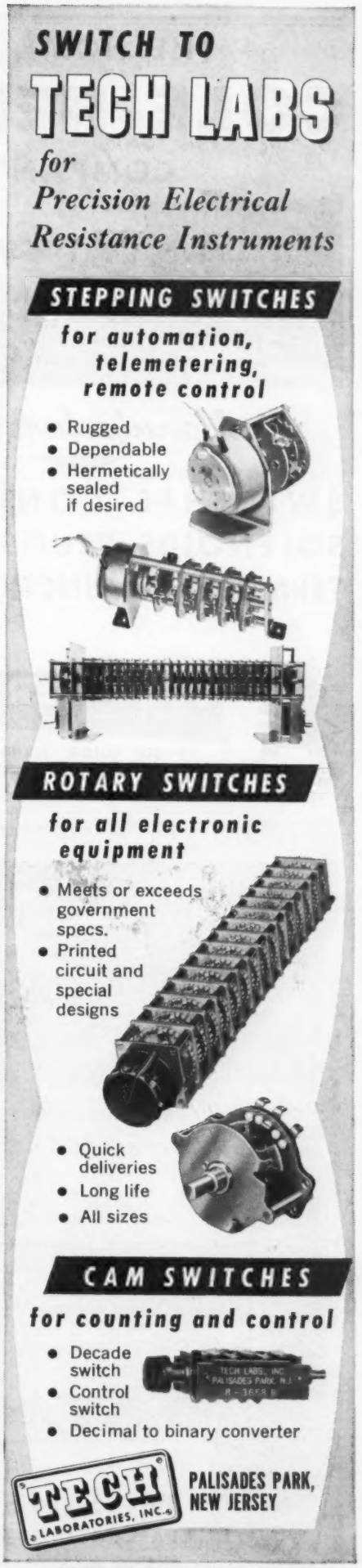
Circle No. 207 on Inquiry Card

WORTH FILING

Inductosyn: Principles and Applications

32 page bulletin tells of Inductosyn automatic machine tool control system for micro positioning. Publication describes both linear and rotary types available, contains installation photographs, discusses applications, and demonstrates versatility. Inductosyn system can be adapted to new machine tools or to automate existing machine tools of various types and sizes.

Source: Farrand Controls, Inc. New York, N.Y.
For your copy: Circle No. 152 on Inquiry Card



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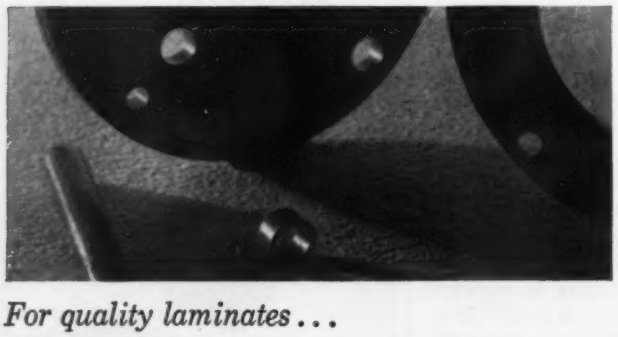

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CIRCLE 14 ON INQUIRY CARD

INDUCTION TRANSDUCERS

Generalized Approach To Design Of Non-Linear Induction Pots

by Dov Malkin

American Electronics, Culver City, California

Induction potentiometers are transducers that develop an output voltage that is a function of shaft input, by varying the magnetic coupling between a primary and secondary winding. They are characterized by infinite resolution, and, in contrast to resistance potentiometers, indefinite noise-free life at relatively high speeds. These properties have been a primary factor in their application.

In Components Digest 3, ELECTROMECHANICAL DESIGN, Feb., 1959 *linear* induction potentiometers were described. Dov Malkin of American Electronics here discusses the generalized approach to the design of *nonlinear* induction potentiometers. The key is to so arrange the distribution of turns on primary and secondary magnetic structures as to achieve the required function of shaft position. Accuracy depends upon the number of available slots for the insertion of windings.

Various types of nonlinear potentiometers can be designed and constructed. Their theoretical accuracy is determined by the number of winding slots on the rotor member and the stator member. The physical size determines impedance levels as well as influencing manufacturing accuracy. A large unit has high input impedance, low output impendance, low phase shift, and fewer errors due to production variation.

In the mathematical presentation given below, an arbitrary distribution of magnetic flux is assumed (with certain logical symmetries). The relative sensitivities of the output windings to the individual flux harmonics is likewise assumed. From these assumed factors, the output voltage as a function of shaft position is established as an infinite harmonic series, each term of which is multiplied by a factor relating to the harmonic flux of the input and a factor proportional to the output sensitivity to the particular harmonic. By comparing this series with a similar series for the *desired* output vs. shaft angle function, the magnitude (and phasing) of the individual harmonic terms are established. The designer must then compromise by selecting coil distributions, using conventional winding theory, to achieve the best match of the actual and required outputs. Only rarely, as in the examples given below, can an exact match be obtained.

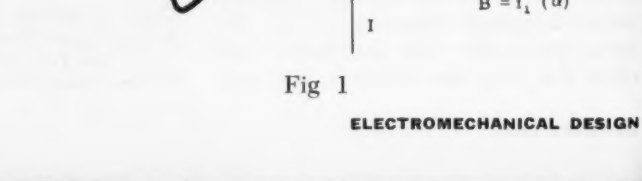
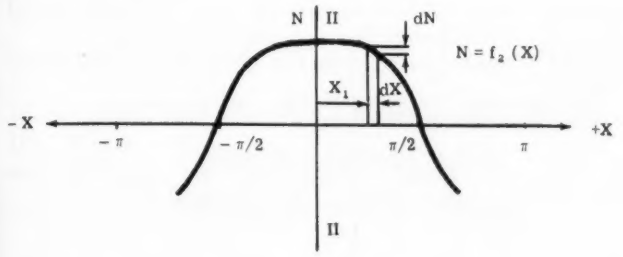


Fig 1

In the following mathematical development, Fig. 1 represents the distribution of flux density along the periphery of the air gap diameter. For simplicity, let us assume skew symmetry for $\alpha = 0$, and that $B = 0$ at $\pm \pi = \alpha$, and at $\alpha = 0$. The flux wave shape is determined by the configuration of the coils on the exciter.

The turns (N) on the excited members are of the following distribution



An element of the coil has the span of 2X, and the number of turns is dN.

A double symmetry is assumed for the N function; a symmetry for $X = 0$ and a skew symmetry for $X = \pi/2$, $X = -\pi/2$

The displacement of axis II II from axis I I will be designated λ

$$\alpha = X + \lambda \text{ by inspection}$$

and for the particular case

$$\alpha_1 = X_1 + \lambda \text{ on the right axis of I–I}$$
$$\alpha_2 = -X_1 + \lambda \text{ on the left of axis of I–I}$$

α_1, α_2 define the position of the particular coil.

The flux thru this coil is:

$$\varphi_{eff} = C_1 \int_{\alpha_2}^{\alpha_1} B \, d\alpha \qquad C_1 \text{ is a constant} \quad (1)$$

The voltage generated in the particular coil will be:

$$de = C_2 \, \varphi_{eff} \, dN \quad (2)$$

The total voltage generated in the rotor is

$$E = C_3 \int_{x_1 = 0}^{x_1 = \pi/2} de = C_1 C_2 C_3 \int_{x_1 = 0}^{x_1 = \pi/2} dN \times \left(\int_{\alpha_2}^{\alpha_1} B \, d\alpha \right); \quad C_1 C_2 C_3 = C \quad (3)$$

Expression $B = f_1(\alpha)$ can be expanded in a Fourier series:

$$B_1 \sin \alpha + B_2 \sin 2\alpha + B_3 \sin 3\alpha + \ldots \quad (4)$$

Expression $N = f_2(X)$ can be expanded to

$$N_1 \cos X + N_3 \cos 3X + N_5 \cos 5X + \ldots \quad (5)$$

The K member of the B function will contribute the flux φ_k thru the particular coil

$$\varphi_k = C_1 \int_{\alpha_2}^{\alpha_1} B_k \sin K\alpha \, d\alpha = C_1 B_k \int_{\lambda - x_1}^{\lambda + x_1} \sin K\alpha \, d\alpha$$
$$= C_1 2(B_k/K) \sin K\lambda \sin K X_1 \quad (6)$$

and the voltage generated in the p member of the N series will be

$$E_{kp} = C \, 2(B_k/K) \sin K\lambda \int_{x=0}^{x_1 = \pi/2} \sin KX \, N_p P \sin p x \, dx$$

since $dN_p = N_p P \sin px \, dx$

$$\text{Thus } E_{kp} = C \, (B_k/K) \, PN_p \sin K\lambda \int_0^{\pi/2} [\cos X \, (K-P) - \cos \chi \, (K+P)] \, d\chi$$
$$= R\{[1/(K-P)] \sin (K-P)(\pi/2) - [1/(K+P)] \sin (K+P)(\pi/2)\}$$

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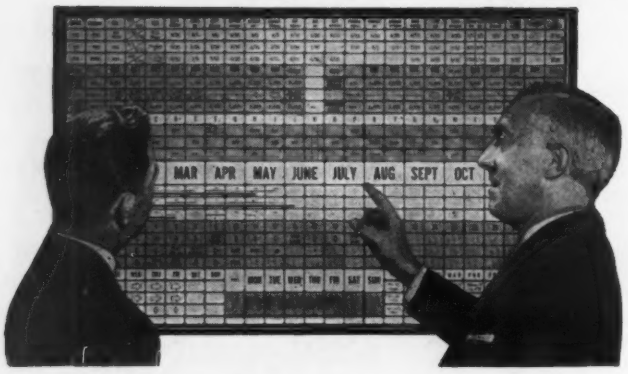

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ACTUAL SIZE

- **Sections** – up to five sections
- **Poles** – up to 6 poles per section
- **Electrical rating** – 3 amp. 115v. a-c continuous; ½ amp. interrupting
- **Voltage breakdown** – 1000 volts RMS
- **Positions** – 2 to 12 positions per section

Sections and rotors molded of MAI-60, per MIL-M-14E. Current carrying parts are made of silver-alloy. Designed for single-hole panel mounting. The shaft is ¼" in diameter.

Write for Bulletin No. 14 for further information.

ESCO of WEYMOUTH
ELECTRO SWITCH CORPORATION
167 King Avenue, Weymouth 88, Massachusetts

CIRCLE 17 ON INQUIRY CARD

There are three general cases:

I. $K = P = r$ in which case $E_{kp} = (\pi/2)\ C\ B_r\ N_r \sin r\lambda$

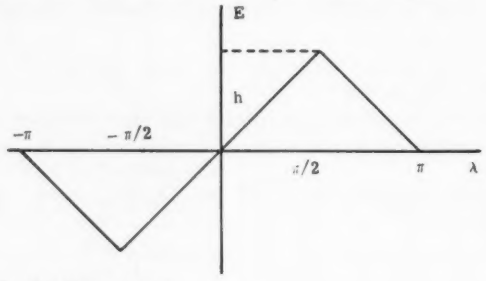
II. K = odd, p = odd or K = even, p = even, $K \neq P$ in which case $E_{kp} = 0$

III. K = even, p = odd or vice versa in which case $E_{kp} \neq 0$

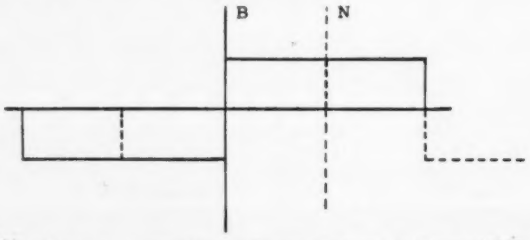
In a series where odd members only exist, for both N and B, Case 1 only will contribute to the rotor voltage.
The total voltage generated in the rotor at a displacement λ will be:

$$E = (\pi/2)C\ (B_1N_1 \sin \lambda + B_3N_3 \sin 3\lambda + B_5N_5 \sin 5\lambda + \ldots) \quad (8)$$

The following examples demonstrate the practical procedure for the construction of the transducer.

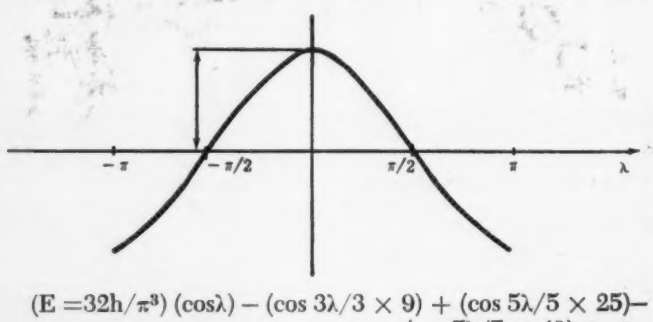


Example 1: linear pot
The equation for linear output is:
$E = (2h/\pi)\lambda$, the Fourier series of which is:
$E = (8h/\pi^2)\ [\sin\lambda + (\sin 3\lambda/9) + (\sin 5\lambda/25) + \ldots]$
From equation (8) we identify
$B_1N_1 = 1$, $B_3N_3 = (1/9)$, $B_5N_5 = 1/25$, etc.
The simplest solution for the B and N series is $B_1 = N_1 = 1$, $B_3 = N_3 = 1/3$, $B_5 = N_5 = 1/5$, etc.
This of course is the mathematical expression of concentric winding both for stator and rotor.



Example 2 is a resolver whose output is sinusoidal; there is a sinusoidal distribution on both its windings and all higher harmonics disappear.

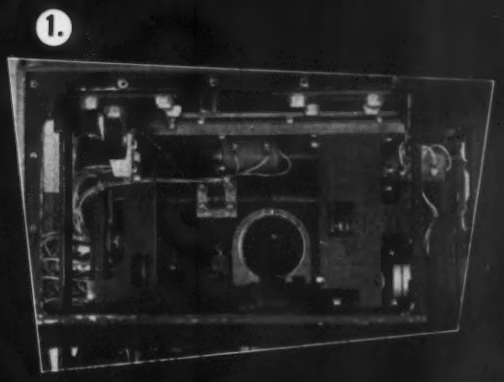
Example 3–Integrating transducer $E = h\ [1-(4\lambda^2/\pi^2)]$



$$(E = 32h/\pi^3)\ (\cos\lambda) - (\cos 3\lambda/3 \times 9) + (\cos 5\lambda/5 \times 25) - (\cos 7\lambda/7 \times 49) + \text{etc.}$$

This can be achieved by the following series:
$\cos\lambda + (\cos 3\lambda/9) + (\cos 5\lambda/25) + (\cos 7\lambda/49)$ etc.
which is the expression for a triangular distribution of wedge and:
$\cos\lambda - (\cos 3\lambda/3) + (\cos 5\lambda/5) - (\cos 7\lambda/7)$ etc.
which is the expression for square concentric wedges.

To ELECTRO-MECHANICAL ENGINEERS who are interested in designing and developing



1. Portion of Navigational Display Mechanism
2. Flight Interrupter
3. Reticle Frame for Navigational Display
4. Experimental Magnetic Memory Drum

PROTOTYPE HARDWARE

The Hughes Systems Development Laboratories have dozens of openings for Electro-Mechanical Engineers ... to design hardware to meet the severe environments of space vehicles, missiles and all-weather interceptors. This is an opportunity for design engineers to utilize their ingenuity and creativity in the development of complex precision electro-mechanical devices which must be highly efficient and reliable.

These positions provide, perhaps uniquely, for individual professional satisfaction through participation in the performance analysis of your own creations.

Some of the areas of assignment are:

- Infra-red Devices
- Digital Computer Devices
- Gyroscopic Guidance Devices
- Inertial Guidance Devices
- Flight Simulator Equipment
- Missile Control Devices
- Antenna Control Devices

Ideally, applicants should have at least two years of practical professional mechanisms experience and an accredited E.E., M.E., or Physics degree.

If you feel that you can contribute, please airmail your resume to:

Mr. Robert A. Martin, Supervisor Scientific Employment
HUGHES RESEARCH AND DEVELOPMENT LABORATORIES
Culver City 75, California

HUGHES

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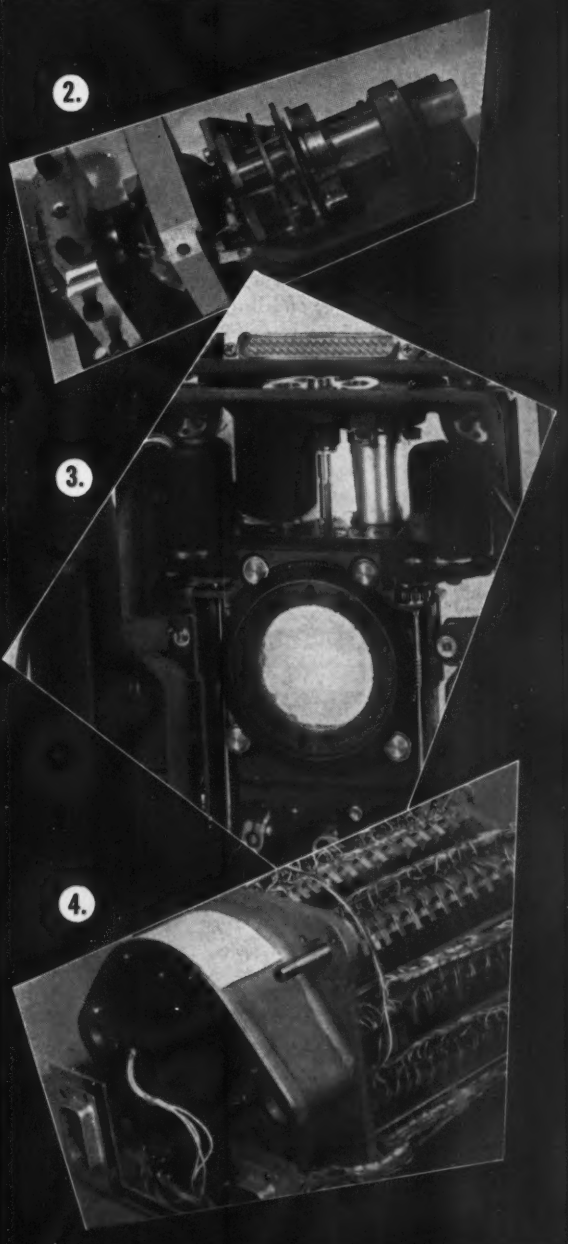


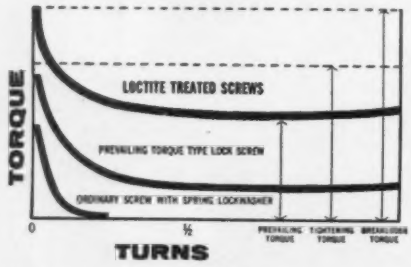
Stake screws with LOCTITE ...a retaining compound designed for thread locking!

Insulating varnishes and mechanical punching have been widely used for years for the lack of a better method. Now there is a retaining compound designed specifically for thread locking. Consider these advantages:

1. LOCTITE provides complete resistance to loosening under shock or vibration because it fills and locks engaging threads, providing *both* breakloose and prevailing torque.
2. LOCTITE has several times the holding power of locknuts or lockscrews because locking action extends over entire engaged surface and persists for several turns.
3. LOCTITE is easy to apply . . . not sticky . . . no mess . . . does not air dry! Hardens only in absence of air. Large batches of threaded parts can be treated and stored for days . . . lock only when assembled. No heating or mixing is necessary.
4. LOCTITE comes in different strengths which apply any required locking torque—ranging from a light drag suitable for adjustment screws to a locking force exceeding the torsional strength of the screw. Provides greater uniformity than mechanical staking.

LOCTITE MEETS MIL-P-11268D

LOCKING CHARACTERISTICS OF LOCTITE



LOCTITE is a thin liquid that hardens when confined between closely fitting metal parts. It forms a tough, heat and oil-resistant, bond that secures threaded parts better than any mechanical locking device. Write for literature and free sample.

LOCTITE® SEALANT

AMERICAN SEALANTS COMPANY

109 Woodbine St., Hartford 6, Conn.

In Canada: J. S. Parkes & Co., Ltd., Montreal

CIRCLE 18 ON INQUIRY CARD

COMPONENTS DESIGN

4-Way Solenoid Valve

New 4-way corrosion-proof solenoid valve, with full ⅛ orifice (0-300 psi) to 3/16 orifice (0-90 psi) has only two internal moving parts and completely protected solenoid coils. Internal media does not pass around solenoid plungers. The coils are completely sealed from air, oil, gas and water . . . and will not overheat on continuous duty. Coils for continuous or intermittent duty, a-c or d-c, are interchangeable. Life expectancy is many millions of cycles, and by inserting two new one-piece valve plungers, many millions more can be expected. The plungers can be replaced without disturbing rigid piping. Airmatic Valve, Inc., Cleveland, Ohio.

Circle No. 139 on Inquiry Card

4-Stage Amplifier

Smallest 4-stage amplifier is available in production quantities. It is .531 x .228, weighs 1/16 of an ounce, has a gain of 73 to 78 db at 1 KC with 1000 ohm load, input impedance of 2000 ohms; signal to noise ratio of 42 db below 1 volt; current drain is 2.1 milliamperes maximum from 1.3V cell. Centralab, Milwaukee, Wisconsin.

Circle No. 136 on Inquiry Card

Explosion-Proof Pressure Control

New, waterproof, explosion-proof, high pressure control, suitable for air, gas or liquid pressures in hazardous locations has pressure setting made by turning a knurled knob against a calibrated dial. The setting may then be locked with an allen wrench to avoid unauthorized tampering. A tamper proof screw-on cap is also provided for additional protection. Pressure ranges of this new control extend from 10 psi to 1700 psi, with a proof pressure of 2500 psi and a maximum pressure of 3500 psi. Cast iron base and aluminum cover construction permits the use of this control in Class I, Groups C & D; Class II, Groups E, F & G; Class III as defined by the National Electrical Code. Approximate weight 8 lbs., 7 oz. switches available include normally open, normlly closed, or double throw with no neutral position, and are rated for 15 and 20 amps at 115/230 volts AC. All switches are single pole and suitable for ambient temperatures up to 180F. United Electric Control Co., Watertown, Mass.

Circle No. 147 on Inquiry Card

250 Amp Silicon Rectifier

Low thermal drop (less than 10C junction to base) and low junction temperature rise (approximately 60C) are built-in features in a new series of half-wave silicone rectifiers rated at 250 amperes d-c. This combination minimizes "thermal-aging" problems and extends life expectancy. Either positive or negative base polarity is available. Designed for use in welding, electroplating and electrolysis application, this series is also useful in any application that requires 1000 or more d-c amperes. Sarkes Tarzian, Inc., Rectifier Div., Bloomington, Indiana.

Circle No. 214 on Inquiry Card

Signal-Conditioning Equipment Fits Standard Data-Handling Racks

A new analog signal-conditioning equipment is designed for mounting on standard 19-inch data-handling racks.

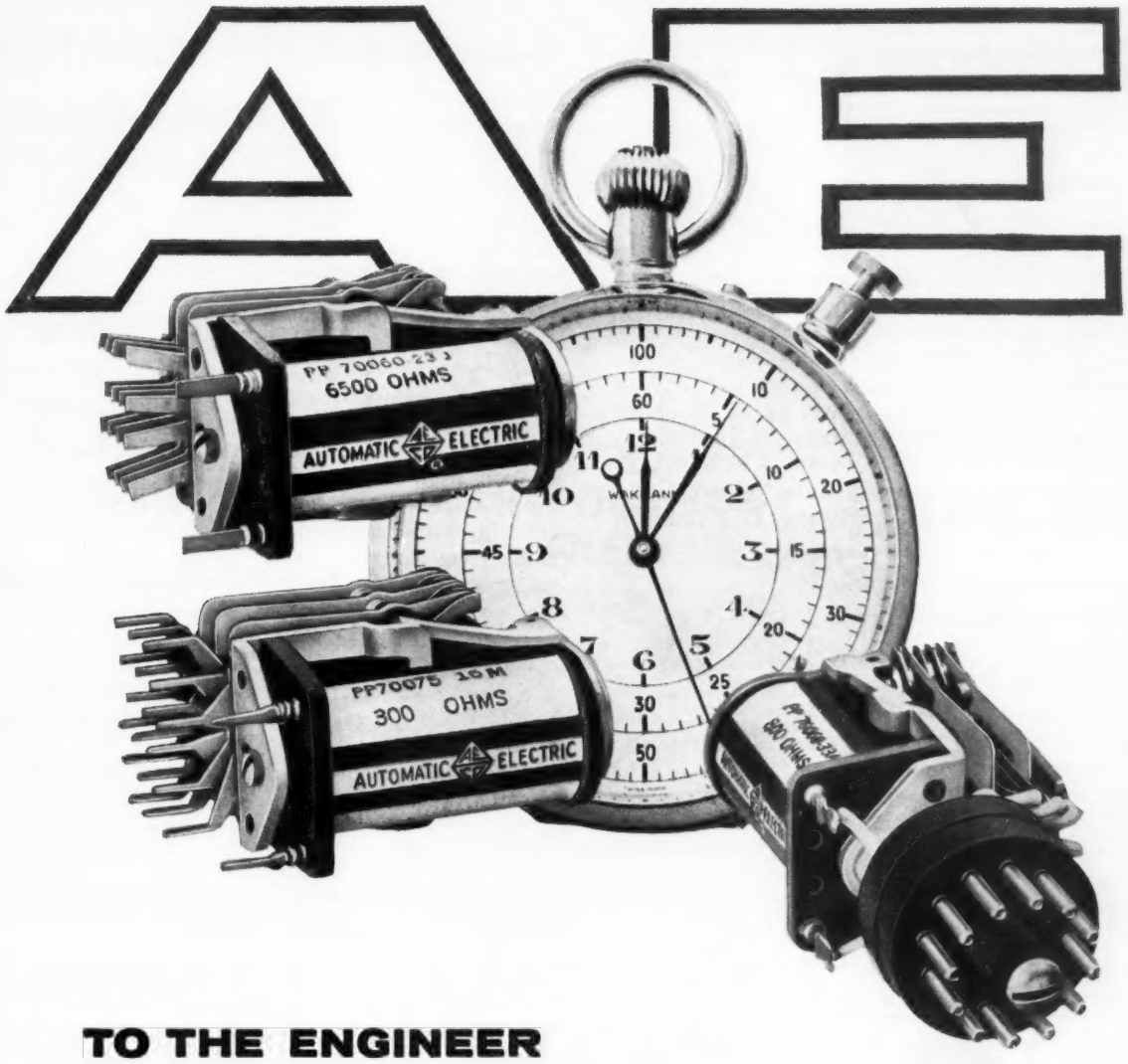
Components in CEC's Type D Amplifier System for amplifying low-level voltages from transducers now have aluminum front panels for rack mounting, and connectors, including power input, have been moved from side to back. The new components are Type 2-105AMB Oscillator-Power Supply and Catalog No. 1-015 Amplifier Case, which houses four amplifiers. Models are still available for aircraft or other applications not involving rack mounting. In addition, an accessory 1-017 Rack Mounting Panel is being manufactured for the Type 1-127 Carrier Amplifier. The panel, which can be installed on units already in use, is flush with the rack, but controls are recessed. Consolidated Electrodynamics Corp., Pasadena, Cal.

Circle No. 125 on Inquiry Card

Miniature Floating Integrating Gyro

New series of high-accuracy miniature floated rate integrating gyros, two inches in diameter and 2¾ inches long and designed for use in missiles or severe missile-like environments, combines the torque motor and the signal generator in a single unit, or "torsyn," together with a restraint-trimming tertiary winding. Designed for maximum adaptability to precision mass production methods, these gyros can be produced having variety of performance characteristics tailored to specific applications. Kearfott Co., Inc., Clifton, N.J.

Circle No. 230 on Inquiry Card



TO THE ENGINEER

looking for a quick connection

Engineers out to cut costs at no expense of reliability can count on dramatic savings in assembly and wiring time by designing around AE Class E relays with quick-connect terminals.

Series EQPC is designed for direct insertion into printed circuits. Series EQTT, with Taper-Tab terminals, provides firm, high-conductivity connections without soldering.

AE also supplies Class E relays prewired for plug-in – with standard 8- to 20-prong octal plugs. Where additional relay protection is essential, the plug-in types are available in hermetically sealed containers or with dust-tight housings and hold-down brackets.

The AE Class E relay is a miniaturized version of the premium-quality Class B, with many of its best features. Perfect contact reliability exceeding 200 million operations is common.

AE is also equipped to supply wired and assembled, custom-built control units, *or to help you develop complete systems.*

Want details? Just write the Director, Control Equipment Sales, Automatic Electric, Northlake, Illinois. Also ask for Circular 1702-E on *Relays for Industry*, and the new 32-page booklet on *Basic Circuits.*

AUTOMATIC ELECTRIC GENERAL SYSTEM

Subsidiary of

GENERAL TELEPHONE & ELECTRONICS

CIRCLE 19 ON INQUIRY CARD

COMPONENTS DESIGN

Automatic Controlled Rectifiers

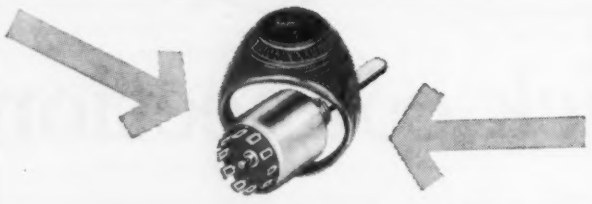
A complete line of fully automatic inductro-capacitron regulator controlled selenium, germanium and silicon rectifiers have been developed for laboratory, computers, electroplating, machinery, industrial and military applications. These d-c power supplies with voltage or current sensing device provide constant voltage or constant current within ±0.1% regardless of load variations from 0 to 100% or line variations within ±10%. The power factor is up to 100% and efficiency up to 96%. The units are available in different ratings from 100 watts up to 500 KW with normal convection, forced air, oil convection or oil circulating cooling. DJECO, Div. of Djordjevic Engrg. Co., Chicago, Ill.

Circle No. 170 on Inquiry Card

Thermal Relay For Missiles

Hermetically sealed thermal time delay provides operation under vibration of 20g up to 2000cps and under shock of 50g for 11 ms. There is no resonance below 2000cps and extended exposure to these conditions causes no damage or change in characteristics. Operating time delays of 3 to 60 seconds are available. Time delay is factory set within a tolerance of ±5%. Effects of ambient temperature have been greatly reduced and are held to ±5% over the range of −65C to +125C. Heater voltages range from 2 to 115 volts for delays of 3 to 12 seconds and from 2 to 230 volts for the longer delays. G-V Controls, Inc., Livingston, N.J.

Circle No. 164 on Inquiry Card

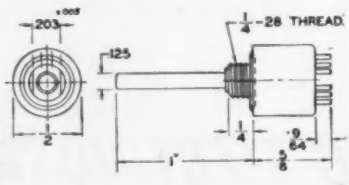


THE SMALLEST ROTARY SWITCH EVER MADE!

Daven's New Series G Sub-Miniature Switch, 1/2" Diameter!

A new sub-miniature rotary selector switch, developed by DAVEN, is specifically suited for application in missiles, aircraft, handy talkies, field pack sets, frog-man communication equipment, and all types of mobile apparatus. This explosion-proof, waterproof switch has the same reliability as its bigger brothers... but in a fraction of the space. It meets applicable military specifications on temperature, humidity, corrosion, vibration, acceleration, shock and immersion.

This unit is available as a single pole, 10 position switch and can be obtained with up to four poles on a single deck.



THE DAVEN CO.
LIVINGSTON, NEW JERSEY

Write today for comprehensive technical report on the new Series G Sub-Miniature Rotary Switch.

CIRCLE 20 ON INQUIRY CARD

Polarization Switch

Polarization switch filters out radar images of storms and heavy clouds increasing radar range between five and ten times the present maximum in storms. Westinghouse, Pittsburgh, Pa.

Circle No. 232 on Inquiry Card

Isolated Power Supply

Isolated power supply provides up to 1 ampere of current at any regulated voltage between 0 to 20 volts, d-c, for applications in which the ultimate in ripple and noise, regulation of output with line variations and isolation from power source is required. Operating in the capacity of a "floating battery" the Model 21 provides absolute isolation from line voltage and line ground, through the use of unique circuitry. Isolation achieved is truly outstanding, with capacitances of less than 2.5 micro-micro-farads from output to line voltage and from output to line ground and chassis. With the chassis grounded, the total capacitance of output to line voltage is reduced to 0.1 micro-micro-farad. Leakage resistance is greater than 50,000 megohms. Ripple and noise are less than 100 micro-volts (rms) while a 10% variation in line voltage will produce less than 10 milli-volts change in output. Low internal impedance, negligible drift and a low temperature coefficient are other characteristics. Moeller Instrument Co., Electronics Div., Richmond Hill, N.Y.

Circle No. 165 on Inquiry Card

High-Low Temperature and Altitude Chamber For Radiation Testing

Unique environmental chamber tests products and materials undergoing radiation exposure. The three cubic foot test chamber has an adjustable temperature range from +180F to −80F. Altitude can be controlled from sea level to 100,000 feet in fifteen minutes time. A steam vapor generator provides up to 100% relative humidity in the chamber. The water supply reservoir is mounted directly on the unit so that, except for the electrical service, it is completely portable on four 6" casters. Radiation in the chamber is accomplished by a 1" diameter non-metallic tube that penetrates through the chamber and extends 6" on each side. A capsule of radioactive material is inserted in the tube for the test. The chamber can be used with or without the capsule in the tube. Other special accessories of the unit include program controllers for wet and dry bulb temperatures and absolute pressure. Cincinnati Sub Zero Products, Cincinnati, Ohio.

Circle No. 168 on Inquiry Card

Kit For Mounting Circuitry

Low-cost, all-in-one tool for rapid construction of resistor boards, turrets, vertical plane circuits, plug-in units, etc., for prototypes and small production runs provides a faster, easier method of mounting standard components. It is also a logical means to get started with plug-in unit construction. This universal tool punches terminal holes, swages terminals, eyelets sockets, and rivets brackets by simply changing punch and anvil; makes it simple to lay out your schematic in production form and move directly to circuit wiring. Unique ratchet terminals included in kit make it simple to mount components quickly and securely, even on a production basis. Components simply snap into ratchet jaws which hold leads for soldering instead of twisting around a post. Alden Products Co., Brockton, Mass.

Circle No. 183 on Inquiry Card

RECHARGEABLE

ECONOMICAL

YARDNEY SILCAD® BATTERIES

You'll use and reuse your YARDNEY SILCAD over 2,000 to 3,000 partial cycles... 300 to 500 complete discharges. Here is true year-in, year-out economy!

This, among other factors, explains why the long-life, maintentance-free YARDNEY SILCAD is being used more and more in military and commercial fields — as a compact, lightweight and rugged power source in portable TV and radio and tape recorders . . . in radio-controlled models... in electric cars and trucks . . . in photographic equipment such as lighting, photoflash and camera drives . . .

YARDNEY ELECTRIC CORP.

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*"Pioneers in Compact Power"**

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Patents granted and pending.
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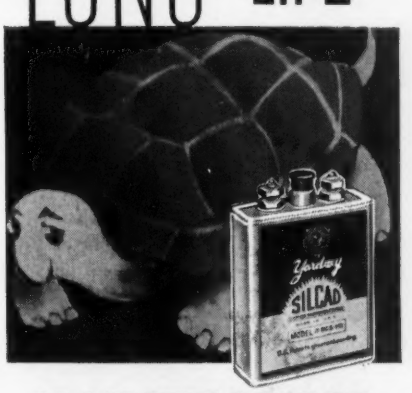
LONG-LIFE



MAINTENANCE-FREE

YARDNEY SILCAD® BATTERIES

Nothing to add, nothing to fix. With the compact, powerful, rechargeable SILCAD you can forget about maintenance!

For this reason — and many others — design engineers in military and commercial fields have turned to the rugged, lightweight, economical YARDNEY SILCAD to meet the demands of today's portable electronics — receivers, transmitters, computers, transverters, converters, solid state inverters, and all portable electronics... heavy-duty lighting, internal and ground support APU replacements, marine equipment, page-call systems, stand-by power... portable medical equipment . . .

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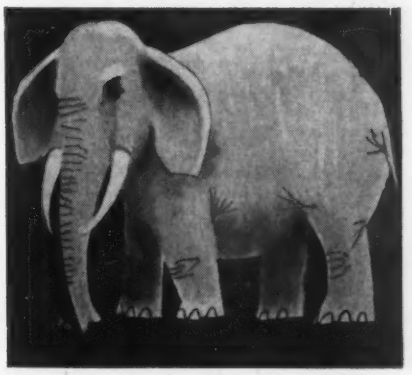
LIGHTWEIGHT

RUGGED



YARDNEY SILCAD® BATTERIES

Only ½ the size, ⅓ the weight of ordinary nickel-cadmium and lead-acid batteries . . . yet rugged enough for the most adverse conditions!

This is one reason industry is now designing with the long-life, maintenance-free YARDNEY SILCAD — economical, compact, rechargeable power for missiles, rockets, satellites and drones . . . for guidance, control, telemetering, storing energy supplied by solar energy converters . . . for such airplane and helicopter applications as engine starting, emergency lighting, power and communications . . . for portable ground power . . . and numerous commercial applications.

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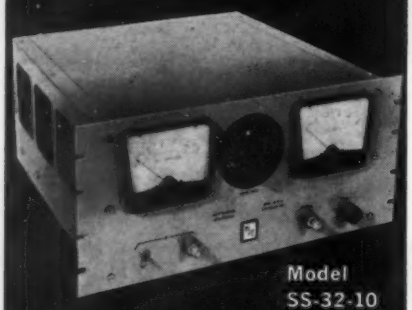
CIRCLE 21 ON INQUIRY CARD

re-
liability!

In NJE Solid State Transistorized Power Supplies every component is the highest quality military or commercial type available (example: every transformer and choke is a MIL-T-27A style unit, every resistor is wire-wound). All are significantly derated under the most severe combination of line, load and ambient conditions. Proven reliability makes NJE your best Power Supply buy! 14 standard models cover virtually every job. Here's one:

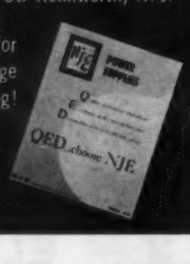


Model SS-32-10

Output, volts: 0-36.
Output, amps: 0-10.
RMS ripple: 1 millivolt.
Regulation, load: ±0.015% or ±1 MV.
Regulation, line: ±0.03% or ±2 MV.
Internal Impedance DC-20KC: 0.04 ohms.

PRICE: $750
FOB Kenilworth, N. J.

Write today for this new 16-page Power Supply catalog!



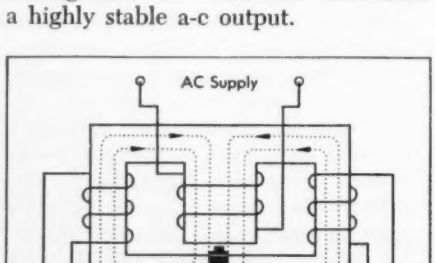
NJE
CORPORATION
20 Boright Ave., Kenilworth, N. J.
Br 2-6000
CIRCLE 22 ON INQUIRY CARD

NEW TRANSDUCER PRINCIPLE

High-Level Electrical Response From Minute Physical Motion

A new principle—known as Metrisite—incorporated in a variety of displacement and velocity transducer forms now in production by Brush Instruments, Div. of Clevite Corp. in Cleveland, Ohio represents a basic improvement in the differential transformer principle widely used in transducers.

Only one moving part is involved, an extremely lightweight armature suspended in an air-gap of a laminated magnetic structure, (see illustrations). Movement of this armature from center produces an imbalance in flux distribution in direct proportion to the degree of travel. The difference in voltage of two secondary circuits resulting from this imbalance constitutes a highly stable a-c output.



The Metrisite Principle—Field excitation in closed-loop transformer is symmetrical when armature is at center, becomes asymmetrical when armature is displaced. Off-center field induces differing voltages in secondary coils. Secondaries are connected in series and opposed. Output voltage is proportional to their flux difference, which in turn is proportional to their flux difference, which in turn is proportional to displacement of armature.

Because the armature has very low mass and is non-magnetic, energy needed to move it is slight and reaction on the mechanical input is negligible. Excellent resolution at null-point, mid-range and full-scale eliminates problems of "hunting" close to the null or signal decay at extreme range.

PERFORMANCE

Metrisite transducers exhibit linearity several orders of magnitude better than comparable synchro, LVDT or other electro-magnetic types. Production models have a proven linearity of 1/10%. Zero stability is exceptional, with repeatable response to displacements as minute as 0.0001″. Resolution is limited only by the mechanical structure with which the device is used.

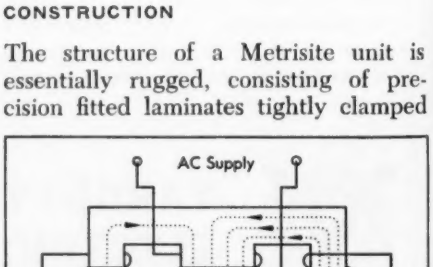
A typical Metrisite transducer currently used in a well-known industrial control has an output of approximately 1 volt across a 330 ohm load in response to a movement of 0.2″. Special units can be made with outputs as high 100 volts. This relatively high output combined wtih a low background noise level greatly simplifies design of associated equipment. As an example, a sensitive rectifier type meter can be operated directly *without* an amplifier.

Operated on a 60 cycle line, full scale operation of a suitable meter is obtained from movements as small as 0.005″. With suitable amplification, full-scale response may be obtained from displacements of 1 microinch. Designs have proven practical well above the audio range.

The Metrisite principle adapts readily to a great variety of configurations from the very minute to sizes capable of measuring a motion travel of four inches or more. Special arrangements can extend the practical range by a large multiple. Units are in production to measure angular or purely linear movements.

CONSTRUCTION

The structure of a Metrisite unit is essentially rugged, consisting of precision fitted laminates tightly clamped



between monoblock castings. The armature does not contact the structure at any point when in operation. Compact and light in weight, Metrisite transducers can meet difficult miniaturization and weight-saving requirements—hence are adaptable for use in missiles, aircraft and portable instrumentation systems. They are virtually unaffected by temperatures over a wide range, or by moisture or vibration.

Circle No. 88 on Inquiry Card

WORTH FILING

Small Basic Switches

20-page catalog covers four important types of miniature switches. Outstanding features are high capacity, long life and compact control. Models are available in many contact types, terminal designs and assemblies. One type is a sub sub-miniature switch which, according to the manufacturer, is the smallest single-pole, double-throw snap-action basic switch made to date. Typical auxiliary actuators and assemblies are shown with each of the four types.

Source: Microswitch, Div. Minn-Honeywell Freeport, Illinois

For your copy: Circle No. 206 on Inquiry Card

ARE YOU STILL LOOKING FOR A CHIEF DESIGN ENGINEER?

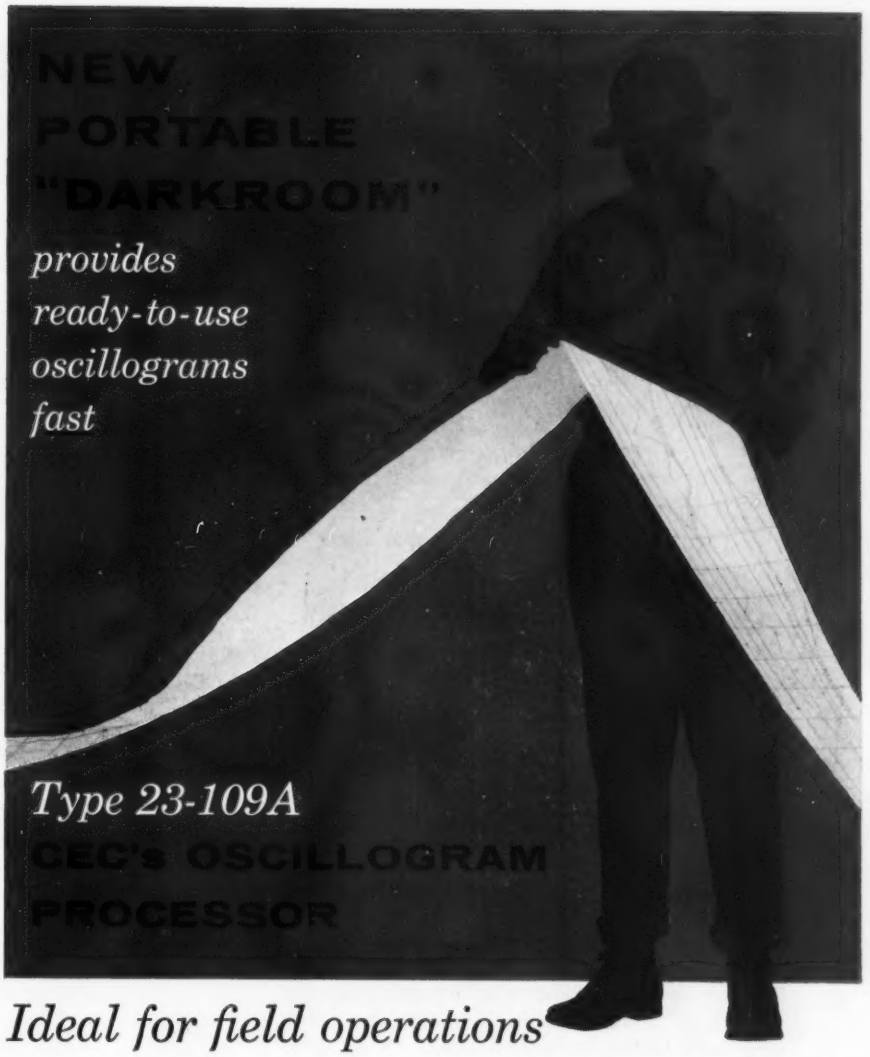
I'm an M. E. who has developed and designed automatic machinery for the production of electron tubes, crystal diodes, whisker leads, wire wound resistors and other electronic and electromechanical components.

In addition, I've designed ovens, honeycomb core machines, machine tools, textile machinery, materials, and chemical processing equipment.

Background includes Harvard Engineering degree and graduate courses in mechanics, materials, electronics, and solid state Physics. Currently employed in the West Coast area.

If you'd like to see a copy of my resume, just drop a note to:

Box 100
ELECTROMECHANICAL DESIGN
1357 Washington Street
West Newton 65, Mass.



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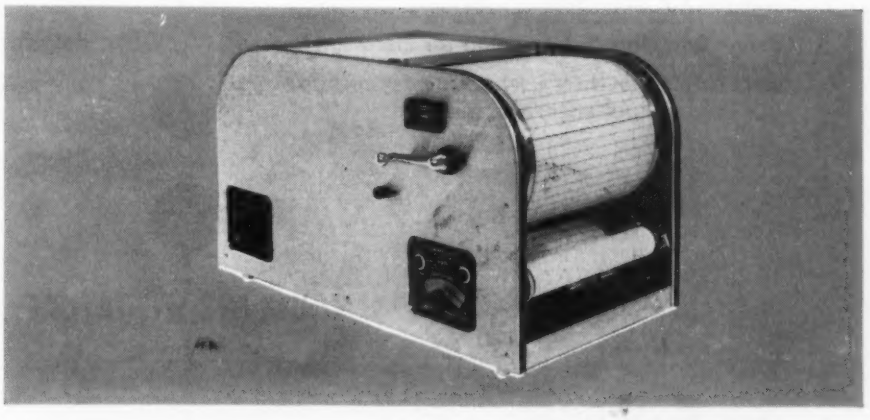

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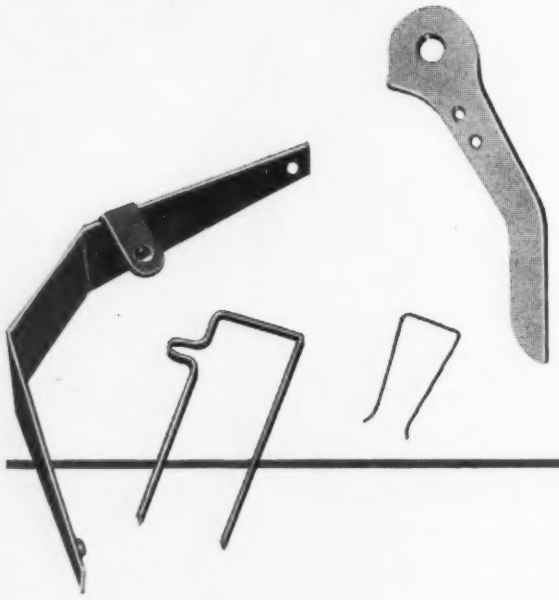

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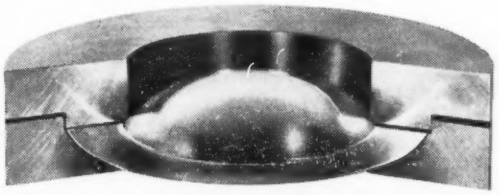

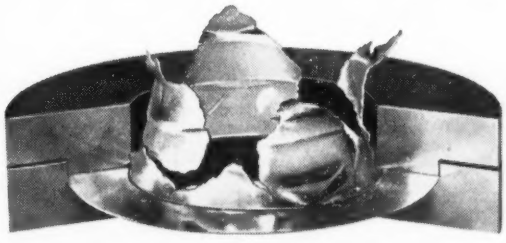

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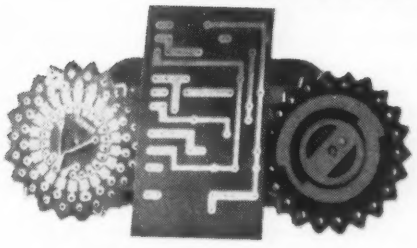

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COMPONENTS DESIGN

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Semiconductor Rectifiers

Six-page technical paper on semiconductor industrial rectifiers gives a basic explanation of the uses and types of industrial rectifiers and covers such topics as monitoring and indicating failures, current and voltage balance, overload protection, voltage surges, cooling, efficiency, and power factor.

Source: Perkin Engineering Corp., El Segundo, Cal.
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Tube Fittings

20-page catalog gives specs on full line of tube fittings. Sections include how to order, "O-Rings" seal hydraulic tube fittings, straight thread fittings, 2 or 3 piece 37° flare tube fittings, and hydraulic accessories.

Source: Lenz Company, Dayton, Ohio
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140 KMC Microwave Equipment

Twelve-page booklet describes a complete line of millimeter wave components and instruments that generate, detect and measure microwave frequencies up to 140 KMC. Units are said to greatly increase user's scope of microwave activity. Performance characteristics, precision construction features, and dimension drawings are supplied for transmission line components, detectors, power absorbing units, horns, tees, frequency and impedance meters, phase shifters, shorts, tuners, and accessories. Text describes many uses for millimeter waves in advanced research.

Source: DeMornay-Bonardi, Pasadena, California
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Resolver Manual

24 page manual is a thorough guide to understanding and application of resolvers. Tightly packed sections include: theory of operation, electrical characteristics, performance characteristics, applications, laboratory testing and performance characteristics.

Source: American Electronics, Inc., Culver City, Cal.
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Variable Speed Drive

16 page catalog describes and gives application information on stepless infinitely variable speed drive. Unit takes any speed at the input, changes speeds instantly at any time, gives positive drive with constant torque throughout speed range, and goes to zero rpm (thus it can be used as a clutch). Available in 35 basic models.

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Transistorized Servo Amplifier

Amplifier with sturdy plug in construction drives either 3.5 watt or 6 watt servo motors from low level 400cps signals. Maximum gain adjusted by external resistor is 2000. Gain stability 3 db over temperature range. Input impedance minimum of 100k at all gains and isolated input makes the amplifier applicable to computing as well as servo designs. Internal limiting prevents overdrive for high input signals. Operates on 28 volts d-c with internal protection against d-c line transients. MIL-E-5272 environmentals. Control Technology Co., N.Y., N.Y.

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Pulse Power Calibrator

Precision instrument directly measures radio frequency peak pulse power with greater accuracy than heretofore achieved by other than calorimetric means. The functions are independent of duty ratio. Display, essentially a notch-wattmeter, is free from parallax. It can be used for accurate calibration of attenuators and for measuring the insertion loss of cables and other RF components. Range is 925 to 1225 mc; −10 to 63 dbm. Power measuring accuracy is within 0.5 db. Relative accuracy when measuring attenuation is within 0.1 db. General Communication Co., Boston, Mass.

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Random Signal Meter

True root-mean-square voltmeter with long averaging time, high peak factor, and extended frequency response is said to be the first such unit designed specifically for high accuracy random signal power measurement, either frequency filtered or broadband. Features include: an exceptionally high peak factor; selectable time constants of 0.5 second and 16 seconds; wide frequency range between 1 cycle and 500 kc; 18 voltage ranges between 0.5 millivolts and 250 volts, extra amplifier and meter outputs, and built-in line regulation. Flow Corp., Arlington, Mass.

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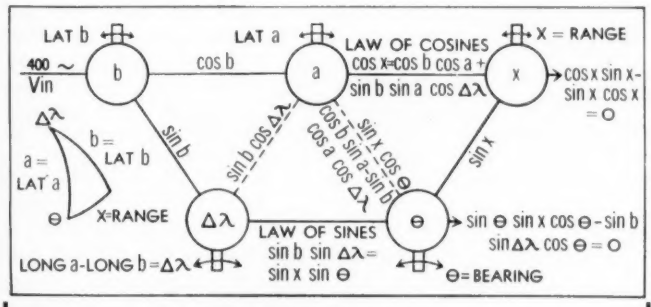

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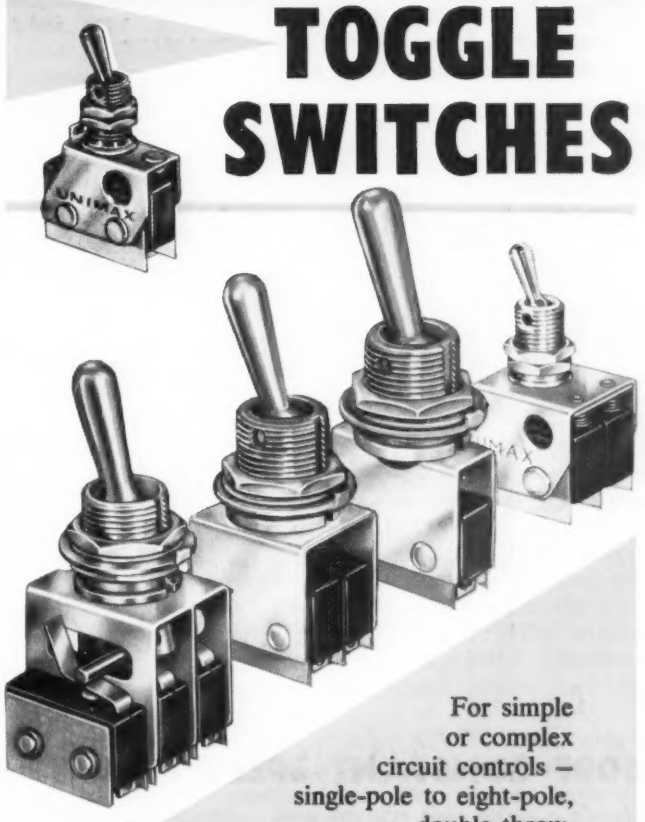
SUBMINIATURE TOGGLE SWITCHES



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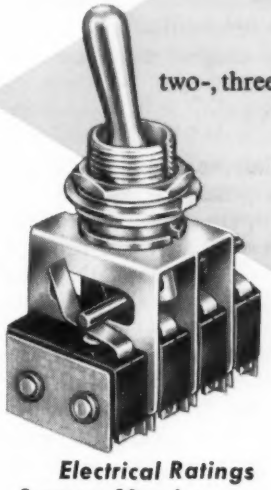
Choice of two-, three-, or five-position toggles in various combinations of momentary and maintained actions.

Basic switches meet MIL-S-6743 and MS-25085-1.



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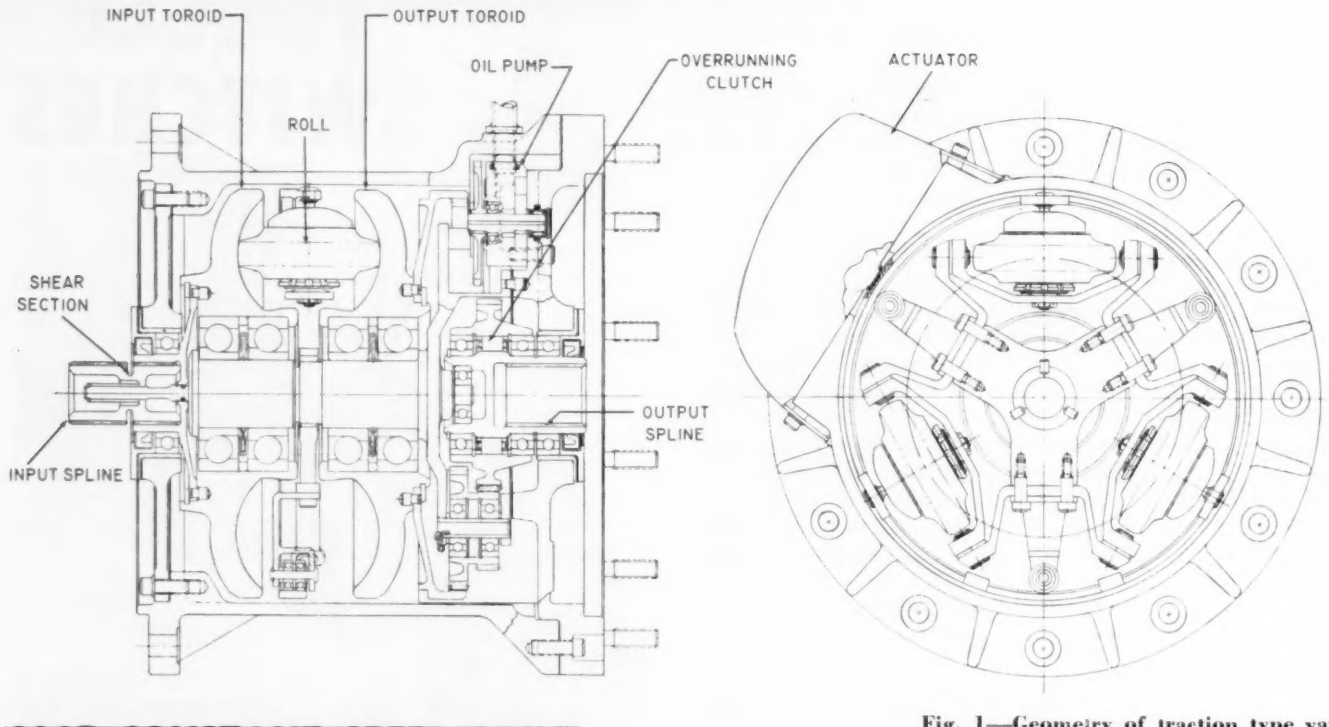

Fig. 1—Geometry of traction type variable ratio transmission used by Avco Lycoming Division in design of a 600F constant speed drive. The roll and toroid geometry employs two adjacent flywheel members called "toroids" which are concentric about the drive axis. Adjacent surfaces of the toroids are dished to form a toroidal space. Rolls are mounted in yokes fastened to a fixed cage within the toroidal space and contact each toroid. Power is transmitted from one toroid to the other through friction because the rolls are mechanically squeezed between the toroids. The rolls are easily "steered" from one roll ang'e to another to vary the speed ratio. The steering technique is similar to that used to steer automobiles or bicycles. Forces required to change speed ratio are thus very low.

600F CONSTANT SPEED DRIVE

Here's a drive that powers and controls aircraft alternators in 600F ambients. The drive is based on a mechanical traction, variable ratio transmission with a mechanical speed control trimmed against an electronic frequency standard.

Some of the problems and milestone achievements experienced by the Lycoming Division of AVCO Corporation in design and development of a 600F constant speed drive of the mechanical traction type for aircraft alternators were described by John S. Jaquith and C. A. Sandner at a recent AIEE Meeting in Seattle, Washington. The project was part of the North American Aviation, Inc. "Hotelec" program. Summarizing Lycoming's accomplishments on the project, they said the fundamental hurdles in developing a 600F constant speed drive had been surmounted:

- Power capability at 600F had been demonstrated with indications of improvements to come.
- Traction transmissions had been controlled well at 600F.

  Suitable materials and lubricants had been found that work together at 600F. Typical mechanical components had operated individually and in combination at 600F. Approximately 90 hours of test at 600F had been accumulated, with many more at temperature above 400F.
- Electronic components and suitable circuits had been operated at 600F.
- A total of about 5,000 hours of test time had been accumulated at this temperature.

The principle work remaining to be done, they said, was the development and qualification of the final article. No major stumbling blocks due to the high temperature were foreseen.

Jacquith and Sandner pointed out that traction-type variable ratio transmissions have been around for many years and that the roll and toroid geometry used by Lycoming (Fig 1.) is not new. The U. S. Patent files show this geometry as far back as 30-50 years ago. But, to apply this type of transmission as a constant speed drive, automatic speed controls were required to adjust the roll position for maintaining constant output speed. Designing the transmission and controls to operate reliably at 600F presented many problems.

The initial Lycoming constant speed drives used all electronic speed controls with electro-magnetic clutches or servo motors serving as the "muscles" to steer the transmission rolls. These initial models were qualified for "oil-in" temperatures of 300F continuously, and 365F intermittently. While the transmission operated at these temperatures, the electrical control box was only required to operate at 257F or below during the test. For a constant speed drive to operate with everything at 600F, the electrical controls had to be uprated in temperature much more than the transmission. For this reason, a mechanical speed control trimmed against an electronic frequency standard was chosen as the most logical approach for the 600F application.

REQUIREMENTS FOR 600F

Requirements for design and development of the 600F system were reported as follows:

- The various parts had to be made

of materials whose strengths are suitable for the temperature and that are compatible with the lubricant.

- The lubricant had to be thermally stable and resist oxidation at the elevated temperatures. In addition it had to be a good lubricant for gears and bearings, while providing high friction coefficients for the rolls and toroids to transmit power.
- The various mechanical parts had to function properly in spite of thermal expansion and changes in moduli of elasticity with temperature.
- The electrical trim control was required to incorporate a frequency standard capable of holding frequency well within the tolerance of the constant speed drive. Electronic component parts had to be uprated to operate in the 600F ambient plus the temperature rise of the trim control itself. A trim actuator which could compare the frequency characteristics of the frequency standard with the output speed and effect a corrective action on the primary speed control was also required.
- The parelling control was required to incorporate a high temperature phase sensitive switching circuit using specially developed relays as well as uprated electronic component parts. Additional switching logic circuits were required to provide a completely automatic system.

TRANSMISSION MATERIALS

The state of the art on materials suitable for 600F operation and higher is well advanced. The problem in selection of materials for the transmission and the mechanical primary control was finding materials with suitable strength and wear characteristics that would work well with the chlorinated silicone fluids necessary for adequate power transmission. Testing programs showed the following materials to be suitable:

Rolls and Toroids–Ferrovac Halmo and T-5 Rex Supercut

Gears–Nitrided inco 5% Ni-2% Al Super Nitralloy and M-10 high speed tool steels

Bearings–Races and Balls–Ferrovac Halmo, M-50 tool steel, 440C Stainless Steel

Cages–Chrome plated S-Monel, iron-silicone bronze

Gear Type Pump Elements–Nitralloy, M-10 tool steel, in a Meehanite housing

Housings and Covers–321 Stainless Steel Weldments

Structural Parts–Vascojet 1000

Springs–Inconel X

Shaft Seals–Graphitar against flame plated tungsten carbide

Gaskets – Duroid 5600, Raybestos Manhattan A56

TRANSMISSION LUBRICANTS

Lubricating and cooling fluid was reported to be an important element in the power capability of a traction type transmission. The principle fluid used for 600F testing was General Electric F-50 with a blanket of nitrogen. Nitrogen prevents oxidation at the elevated temperatures. This fluid is also used in the lower temperature traction transmissions without the nitrogen. At the elevated temperatures, the F-50 fluid gives the proper power capability to the transmission and is compatible with the transmission materials. Other materials that show promise are being tested.

POWER CAPABILITY

The power capability of a traction type transmission was found to be essentially the same over the temperature range up to 600F. Early tests showed a decrease in power with increased temperature. Investigation revealed that the Hertz contact stress between the rolls and toroids decreased as temperature was raised due to decreases in the modulus of elasticity of the various parts. The centrally located "load bolt" preloads the toroid thrust bearings to provide squeeze on the rollers for traction. As temperature rose, the modulus of elasticity decreased in the load bolt as well as the rolls and toroids to reduce squeezing force. In addition, the decrease in modulus gave less Hertz stress for a given force. Testing at various temperatures with constant Hertz stress showed that the power capability remained essentially the same.

To provide constant Hertz stress over the temperature range, the designers used a load bolt of low thermal expansion. The effect was that the preload increased due to thermal expansion of the toroids and rolls to offset decreases in the modulus of elasticity. In addition, they used a "ball screw" as a "variable thruster" to convert overload torques to additional squeeze force. When this is in operation, thermal expansion and modulus of elasticity changes have no effect on the squeeze force.

MECHANICAL PRIMARY CONTROLS

The primary speed control loop employs a conventional type flyball speed sensor feeding into a mechanical traction type velocity actuator which moves the transmission rolls. The actuator (Fig. 2) produces an output velocity that is a function of speed error for isochronous control. Speed load droop is achieved by biasing the speed sensor spring with an output torque signal, so that the speed will fall off with increased load. The electronic trim actuator shifts the actuator null point by means of a differential between the speed sensor and the actuator.

For operation of this control over a wide temperature range, thermal expansion of parts and changes in modulus of elasticity of the governor spring were arranged to offset each other. The prime consideration was to keep the overall effect due to temperature minimized. Alternator frequency should not shift as a result of temperature effects in the primary control. Individual components (transmission, speed sensor, actuator, etc.) could be allowed to shift individually, but the combination of components together could not.

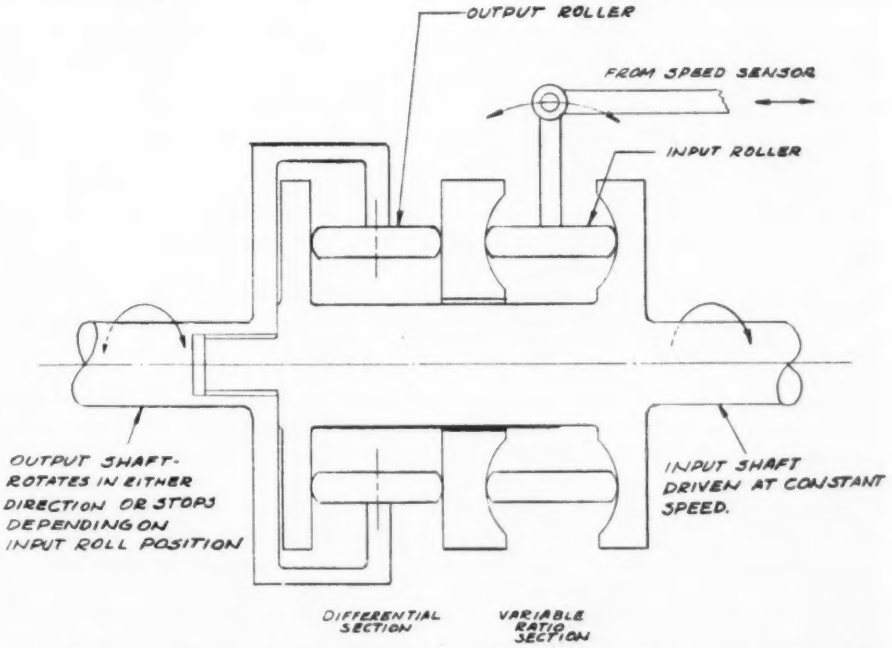

Fig. 2—Mechanical traction-type ve'ocity actuator moves the transmission rolls.

ELECTRICAL TRIM CONTROL

Trimming a device such as the Lycoming mechanical traction type transmission to very close output speed involved three basic problems. The first was the type of actuator to be used, the second was designing an accurate standard for comparison, and third, an amplifier to run the actuator. While all of these things would be relatively simple problems if the 600F ambient temperature were eliminated, they presented very trying problems to the designer who had to make them work throughout the range of temperature ambients specified.

ACTUATOR

Several types of actuators were considered. A servo motor actuator consisting of a two phase inductance motor driving the output shaft through a gear train was first considered. It offered a straight forward approach since work had been done on servo motor designs for this specific ambient temperature range. A second approach was electromagnetic torque motors similar to force motors used on hydraulic servo valves. This device was simple enough that extending its operating temperature range to the high temperature requirement meant simply a change of materials such as wire, insulation, and bearings. A third approach was using electromagnetic servo clutches such as were used in Lycoming's Model XLD-1 transmission and very extensively in automatic pilots. These presented problems of scaling the materials to the temperature requirements, but Lycoming had already operated clutches to 450F and materials existed that could possibly extend this range even further. A fourth method considered was using two synchronous motors driving a differential gear system, generally referred to as differential frequency comparators.

Choice was based on: first, which device had the best chance of earliest completion, second, the method best adapted to systems of frequency comparison and, third, the method of trim that would be most compatible with the mechanical control both in installation problems and dynamics.

The servo motor actuator was considered to have the best chance of early completion. It could be used in a frequency discriminator amplifier circuit with rate generator feedback compensation, and could be geared and damped to a wide selection of conditions. The main stumbling block in this choice was what type of frequency discrimination could be used. The method would probably have to be one using either L-C or R-C type passive networks, and its accuracy would depend upon successfully compensating these networks for the temperature conditions.

The differential frequency comparator was considered next most likely to succeed early in the program. Design of a synchronous motor for the ambient temperatures was not considered greatly different from the design of the inductance motor in the first approach. Development of the differential gears was considered a very difficult problem. However, since the entire program depended upon high temperature gear materials and bearings, this was not considered impossible. The particular appeal it offered was its ease in application. One motor could be run directly from the aircraft electrical system and thus be an accurate measure of output speed since the motor speed depended only upon power frequency over a wide range of voltages. The second motor could be run from a constant frequency oscillator-amplifier employing an accurate frequency standard. Discrimination would occur in the differential gearing since its output speed and direction would depend upon motor speed or frequency difference alone. Voltage would only effect torque in this case, and could be kept constant enough to avoid slippage errors.

Both the torque motors and servo clutches were considered weak third and fourth place devices. While successful high temperature torque motors had been developed, and the chances were very good for servo clutches, they both presented the same type of problems. One, they required the use of an electrical frequency discriminator using passive networks as in the case of the servo-motor; second, both would require a d-c amplifier; and third, both would require a method of integration to prevent hunting between the normal steady state frequency condition and the trimmed frequency condition. Although classical methods of follow-up feedback or passive lead-lag networks were indicated as possible solutions, the temperature ambients would have made the problem extremely difficult. The amount of d-c amplification necessary in the presence of feedback together with the problem of temperature compensating the follow-up or the passive network discouraged this approach.

The differential frequency comparator was selected over the servo motor approach because of the simplicity of deriving an output motion at a rate proportional to frequency error. The actuator in its earliest form consisted of two size 20 synchronous motors and an instrument size set of differential gearing. The line motor is a three phase 115 volt motor. Each motor consumes a maximum power of 40 watts. The motors employ insulation and wire capable of 850F operation to allow for their own rise. Development of this actuator was subcontracted with the John Oster Manufacturing Co.

FREQUENCY STANDARD

In view of the choice of actuator several frequency deviation detection schemes were automatically eliminated. They all fell into the passive network class such as the balanced discriminator using either R-C or L-C networks, the parallel-T networks, and phase detection over an L-C network. All of these employ R, L, and C components in various combinations, the products of which are a contributing factor to frequency accuracy. Fairly good accuracy and sufficiently low temperature coefficients could be found in some of the film-type resistors which on a first glance made the R-C type circuit look quite attractive. Capacitors for 600F and higher were limited to several types of mica capacitors. These in general were considered poor from a temperature coefficient viewpoint and to make matters worse, are subject to aging changes with temperature cycling. While aging gaps are closed with added cycling and it appeared that several cycles would stabilize the capacitors value, nothing was in sight to improve coefficients. Further development of deposited quartz and ceramic units presented a little hope, but units of this type were not available. Inductors were subject to wide variations with temperature in general and very little had been done by the industry to improve the situation. Lycoming had done a small amount of work on compensated inductances and believed the answers lie in the core materials and air gap compensation more than in the inductor configuration and methods of winding it. Accuracies indicated were in the order of less than one percent over the minus 65F to plus 650F range. In view of these facts, compensation of a tuned frequency network appeared discouraging for the immediate future. Lycoming believes, however. that these networks must be considered as likely methods in any future considerations since the state of the art is rapidly being improved.

Of the active oscillator frequency determining components considered, crystals and tuning fork resonators were given the most serious consideration. Although long half-life radioactive materials and master oscillators were considered as possible reference stand-

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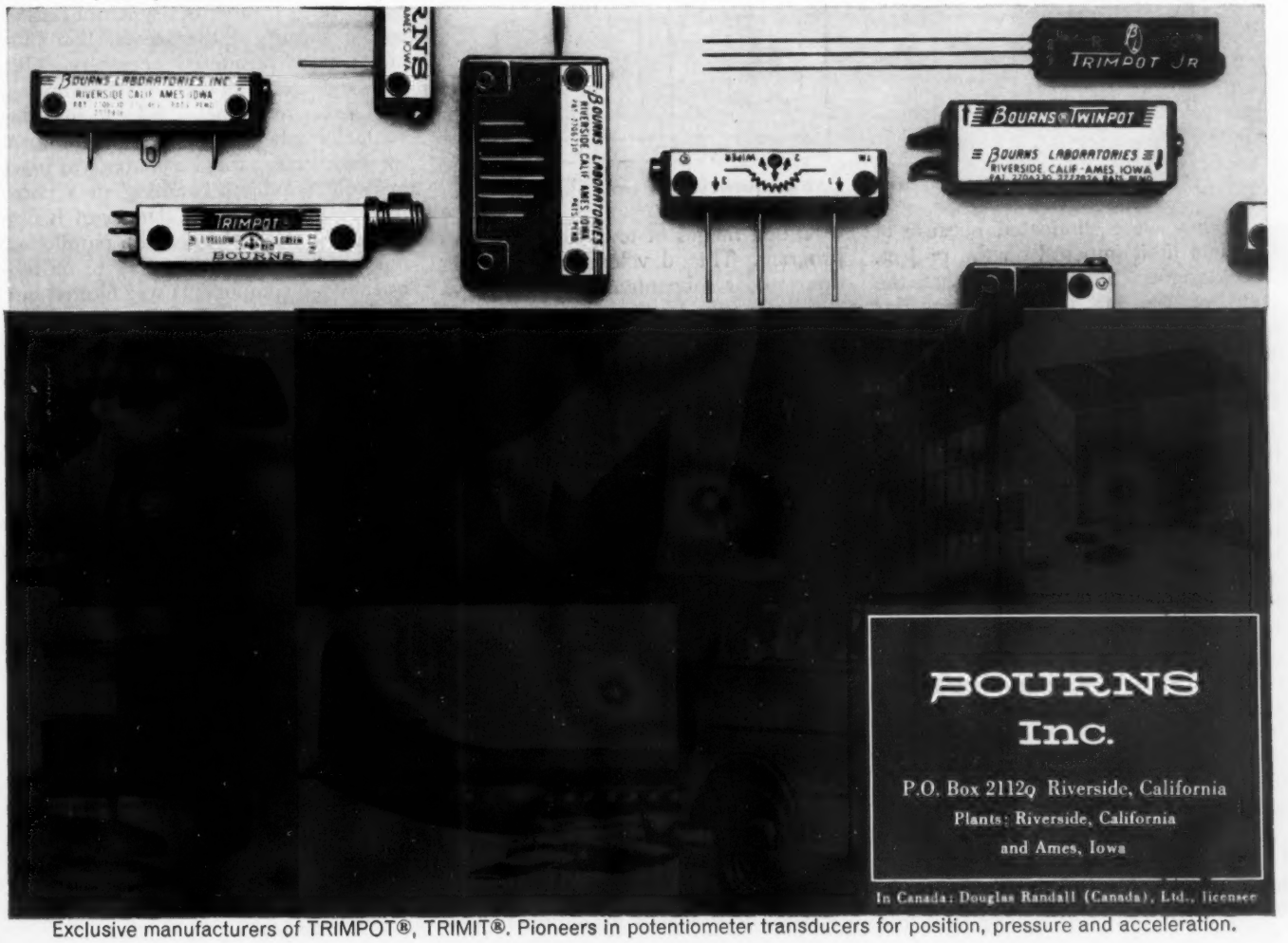

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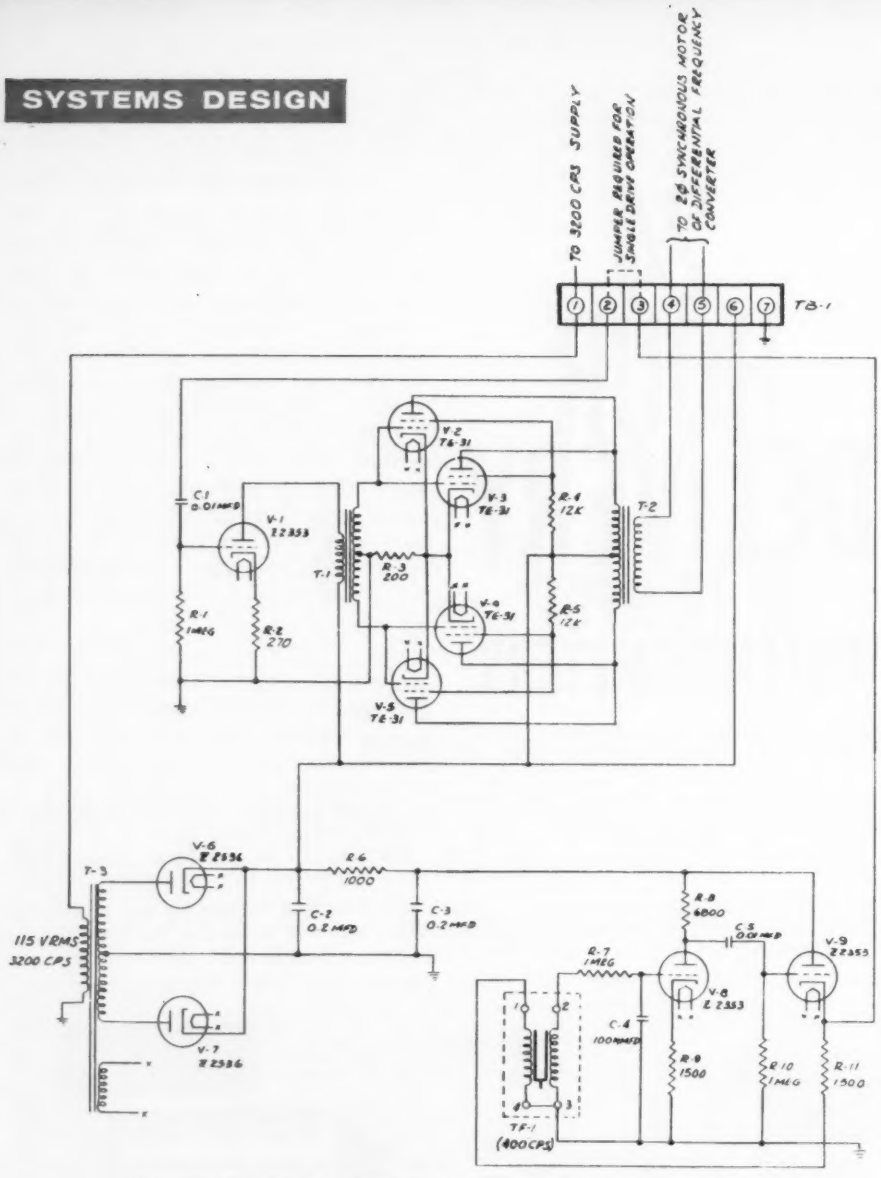

Fig. 3—Schematic diagram of fine frequency trim control.

ards, they were eliminated because of the time limit imposed on the project. The designers did not feel that the state of the art of either was far enough developed. Between crystals and tuning fork resonators, the latter were chosen for two reasons. One was that the crystal manufacturers were not very optimistic as to what could be done with known oscillating materials; the second was that tuning forks employed no more difficult materials than transformers, inductors, and relays and thus stood an excellent chance of success. The present design uses a bimetalic fork with ceramic bobbins wound with ceramic coated silver plated copper wire (Fig. 3). Results were encouraging although a frequency error hump of 0.5 percent occuring between 450F and 600F was experienced. Believing that the answer lies in the bi-metalic materials, Lycoming is conducting extended temperature range tests on modulus of elasticity. One major problem in such a development is that much basic information on materials is not available for the extended ranges of temperature of this program. This development is being done under subcontract by the Bulova Research and Development Labs.

AMPLIFIER

The amplifier used was concerned only with stepping up the output of the tuning fork oscillator to the 115 volt 40 watt condition imposed on it by the frequency comparator. A single-frequency low-response-rate amplifier was sufficient. Ceramic tubes were used in this design because they were available and preliminary tests indicated they were reliable and rugged enough to do the job. Semiconductor amplifiers were out of the question for these temperature conditions because available silicon transistors were limited to 150 to 175C operation. Conventional vacuum tubes were ruled out, although several of the special hard glass types stood up remarkably well under high temperature test. Magnetic amplifiers were out of the question because of the lack of sufficient excitation power in this case. Lack of solid state rectifiers ruled them out.

Conventional amplifier techniques were employed in the interest of design simplicity. It was felt that the component parts of the amplifier presented enough of a problem under the temperature requirements. The greatest problem was in developing the 40 watts of output power with the tubes available. Four Bendix TE-31's were finally used in a push-pull-parallel Class-B amplifier. Sufficient reserve power could be developed to drive the synchronous motor over the temperature range. In the interest of weight and size reduction, by-pass capacitors were eliminated in all cases where it could be tolerated and d-c filtering was reduced to a bare minimum. A toss-up occurred in whether to use a transformer or a phase inverter to drive the Class-B amplifier. A transformer was considered the more reliable, although tests on the phase inverter were considered encouraging. Weights were about equal.

AUTOMATIC PARALLELING CONTROL

Automatic paralleling of alternators on the bus was considered a part of the program. To avoid severe mechanical transients on the transmission and electrical line transients, synchronization before closure of the second line contactor was considered necessary. This involved getting both alternators on the same frequency and closing the contactor when they were in phase. A common tuning fork resonator was used in both amplifiers resulting in a common reference and no danger of beats. A phase detector closed the paralleling relay. Response of the relay to off-frequency a-c components was filtered out by selection of resistor and capacitor values. Compensation was not critical in this case.

The only new components introduced in the paralleling control was relays. They were subcontracted with the Price Electric Company for design and development. Relays perform the paralleling operation and provide cross connection of control to provide starting of either alternator first. All paralleling is performed through the alternator control panel to prevent false commands. Static switching circuits were ruled out in this case for the sake of simplicity and because satisfactory semiconductor rectifier and transistors suitable for this action were not available. Jaquith and Sandner pointed out that the state of the art of semiconductors such as silicon carbide and galium arsenide is rapidly moving forward and would possibly be given favorable consideration at a later date.

Circle 84 on Inquiry Card

DESIGN PROCEDURES FOR SATURATING LINEAR SERVOS

by D. A. PIERRE,
Circuit Development Section
Hughes Aircraft Co.

Increasingly stringent performance requirements have forced servomechanism designers to include nonlinear analysis techniques in their bag of tricks. The simplifying assumption of linearity was simply not accurate enough. Unfortunately there is no one general method for analyzing nonlinear systems. A variety of special purpose methods have been developed to suit different types of nonlinear problems. The method described here is adaptable to the analysis and compensation of saturating servos. It is particularly easy to apply in the area it is designed to cover. The class of servo problems that will be treated have the following essential characteristics: the sensor element has a DC output which is linearly proportional to system output in the null region, but which saturates or is otherwise

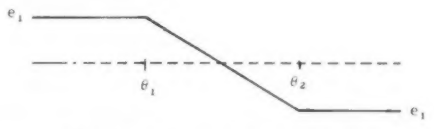

Fig. 1 Sensor Characteristic

limited in certain other ranges. Fig. 1 shows example of this type of sensor characteristic; Fig. 2 illustrates a simple

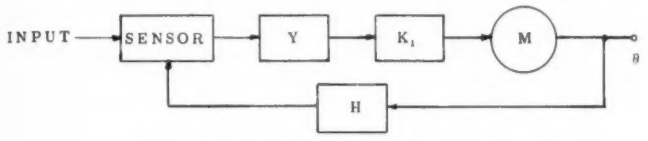

Fig. 2 Simple Loop

loop in which such a sensor might be employed. The remaining elements in the loop are assumed to be linear.

APPROACH:

The theory of describing functions and similar methods of handling non-linear servos of the saturation type are cumbersome, if not impossible to apply, in many cases. Some non-linear saturation servos which cannot be resolved by describing function techniques can be attacked analytically from the following piecewise linearization viewpoint.

If the velocity and the energy stored in any compensating networks are known at the instant the servo enters a saturated region, then these conditions can be reflected to a common input and can be construed as initial conditions enforced on an open loop linear system.

Likewise, if the same conditions are known when the servo leaves the saturated region, then they are to be thought of as initial conditions in the closed loop linear system. Note that since we will be dealing with physical motors whose transfer functions can be approximated by

$$M = \frac{K_2}{S(1 + T_2S)} \qquad (1)$$

the acceleration at the boundry of two regions need not be continuous. Here's the general method in which the above approach can be used.

METHODS

A basic servo loop of the type to be treated, Fig. 2, contains the following elements: a saturating sensor; a motor, M; an amplifier, K_1; an equalizer network, Y; and a feedback element, H. This loop can be redrawn as shown in Fig. 3 by the following reasoning. When the sensor output is in the saturated region, the input is independent of changes in output position and the system can be considered to be operating the open loop mode, i.e., switch S_1

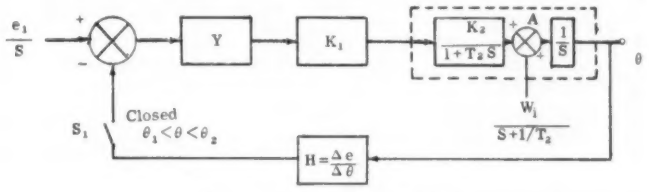

Fig. 3 Equivalent Loop

is open. The switch is closed, however, when the sensor output is in the linear region.

Next, consider what happens at the instant S_1 opens or closes. Fig. 3 shows that the effects of the motor velocity at that instant can be represented by an

$$\frac{W_i}{S + (1/T_2)} \qquad (2)$$

term summed into the loop at point "A". To treat the closed loop problem by the standard transfer function techniques, all the inputs must be common. The initial velocity effect given above can be moved from point "A" to the input by dividing it by the product of the transfer functions included between the input and point "A". In other words, the initial velocity is represented at the input (See Fig. 4) by

$$\frac{W_i T_2}{K_1 K_2 Y} \qquad (3)$$

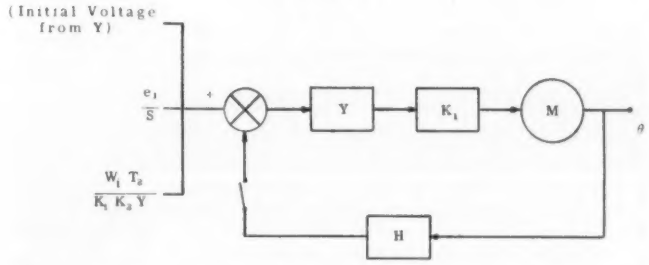

Fig. 4 Initial Loop Conditions Reflected Back to The Input

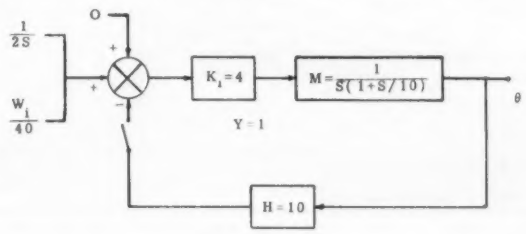

Fig. 5

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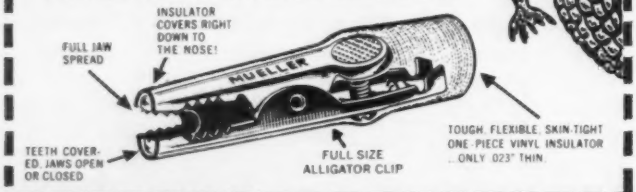
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If Y, K_1 and K_2 are real numbers, this function represents an impulse applied to the system input.

The transfer function of the closed loop system can now be written in the usual manner as:

$$G_T = \frac{K_1 YM}{1 + K_1 YMH} \tag{4}$$

The closed loop response function is:

$$\theta_o = G_T\left[\frac{e_1}{S} + \frac{W_i T_2}{K_1 K_2 Y}\right] \tag{5}$$

where W_i is the velocity at the instant of transit from the saturated region to the linear region. Note that if the switch has been open for considerable time and if Y equals unity, then $W_i = e_1 K_1 K_2$ and

$$\theta_o = G_T\left[\frac{e_1}{S} + e_1 T_2\right] \tag{6}$$

To illustrate the above equations, consider the example of Fig. 5. Assuming that the system has been running with the switch open for a time much greater than the system time constants,

$$W_i = 2$$

$$\theta_o = G_T\left[\frac{1}{2S} + \frac{1}{20}\right]$$

$$\theta_o = \frac{40}{S^2 + 10S + 400}\left[\frac{1}{25} + \frac{1}{20}\right]$$

$$\theta_o(t) = .05 + .103_e{}^{-5t} \sin(19.4t\text{-}0.505) \text{ radians}$$

where time is normalized to zero at the instant of transition. The above function is plotted in Fig. 6, and is graphically compared with the following response that would have been obtained if initial conditions had been neglected.

$$\theta_o(t) = 0.05 + 0.0515_e{}^{-5t} \sin(19.4t\text{-}1.82) \text{ radians}$$

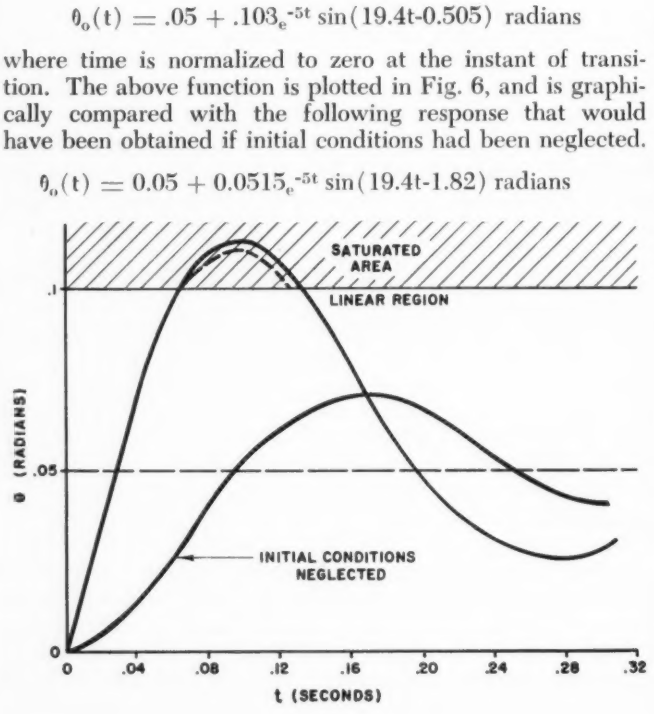

Fig. 6

Note that at t = 0.064 seconds in Fig. 6, the sensor output passes back into the saturated region. The velocity at that instant can be calculated from the slope of the curve and is used in turn as an initial condition in the following open loop transfer function with time normalized to the instant of transition.

$$\theta_o = \frac{40}{S(S + 10)}\left[\frac{0.8}{40} - \frac{1}{2S}\right]$$

$$\theta_o(t) = 0.33\text{-}2(t\text{-}0.064)\text{-}0.28_e{}^{-10(t-0.064)} \quad 0.064 < t < 0.135$$

As can be seen from the curve, the main effect of this

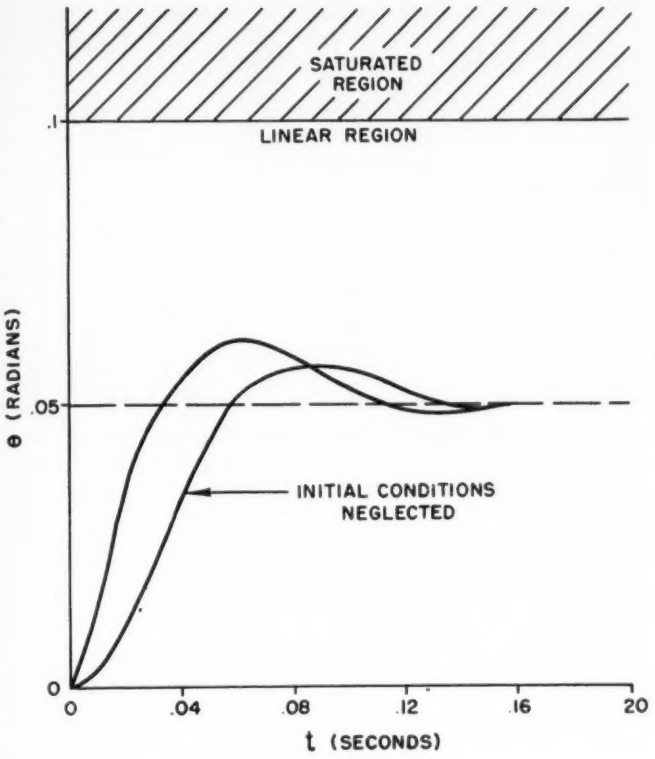

Fig. 7

transgression into the saturated region is to add more delay in the output response.

COMPENSATION

The majority of servo systems use compensating networks to improve system response. Fig. 8 and 9 show two basic types of compensating networks. The effect of initial capacitor charges on the output voltage in these networks can be represented by the summing junctions shown. Since the effect on the output due to an initial voltage in the lead network is opposite in sign to that produced by an initial velocity, it might be expected that this type of network could be used to decrease the initial velocity effect at the same time as it alters the closed loop transfer function for greater stability. This will now be shown to be

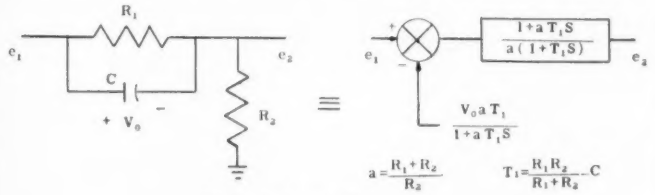

Fig. 8 Lead Network

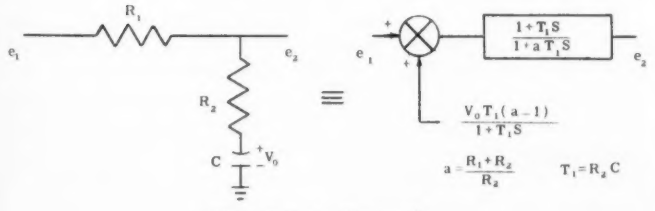

Fig. 9 Lag Network

the case. With use of a lead network in the loop of Fig. 4, Y equals

$$\frac{1}{a}\,\frac{1 + aT_1S}{1 + T_1S}$$

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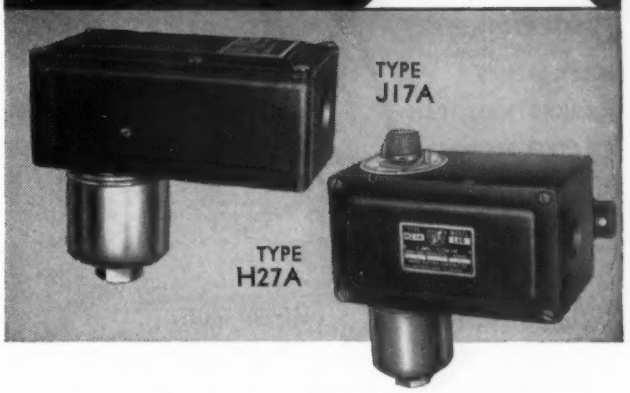

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and the total equivalent voltage at the input is,

$$Ei = \frac{e_1}{S} + \frac{W_1 T_2}{K_1 K_2 Y} - \frac{V_1 T_1 a}{1 + aT_1 S} \qquad (7)$$

where V_1 is the initial voltage across the condenser in the lead network and W_1 is the initial velocity of the motor.

If, as above, we assume that the servo has been running in the open loop mode for considerable time, then

$$V_1 = \frac{a-1}{a} e_1 \text{ and } W_1 = \frac{K_1 K_2 e_1}{a}. \text{ Thus,}$$

$$E_i = \frac{e_1}{S} + \frac{e_1 T_2 (1 + T_1 S)}{1 + aT_1 S} + \frac{e_1 (a-1) T_1}{1 + aT_1 S}$$

$$E_i = \frac{e_1}{S} + \frac{e_1}{a}\left[T_2 - \frac{(a-1)(aT_1 - T_2)}{1 + aT_1 S} \right] \qquad (8)$$

For effective compensation of the closed loop transfer function, aT_1 is usually made slightly smaller than or equal to T_2. When aT_1 equals T_2, equation (8) reduces to

$$E_i = e_1 [(1/S) + (T_2/a)] \qquad (9)$$

A comparison of this equivalent input to the one found in equation (6), shows that the input equivalent of the initial velocity impulse was reduced by a factor of "a".

To illustrate the above, consider the previous example, Fig. 5, with a lead network

$$Y = \frac{1\ (1 + 50S)}{5\ (1 + 10S)}$$

in the forward loop. K_1 must be increased by a factor of 5 so that W_i equals two radians per second as before. Combining equations 4 and 9,

$$\theta = \frac{100 + 2S}{S[(S + 25)^2 + 1375]}$$

$$\theta(t) = 0.05 + 0.06e^{-25t} \sin (37.2t\text{-}2.16) + 0.054e^{-25t} \sin (37.2t)$$

This response and the response of the same system with no initial conditions taken into consideration are plotted in Fig. 7. A comparison of Fig. 6 with Fig. 7 illustrates the benefit obtained by lead compensation.

From the "conditions at transition" viewpoint, use of lag compensation in a servo of the type treated would be detrimental because the initial voltages in the lag network tend to aid the initial velocity, thus causing large overshoots. Lead network compensation on the other hand tends to sharpen the response. The optimum lead network to be used is governed mainly by the desired closed loop transfer function.

SUMMARY

The block diagram method for treating a saturation servo problem can be summarized in the following steps: 1) Place an imaginary switch in front of the saturating element. 2) Replace the initial conditions present in the loop at the throwing of the switch by equivalent conditions at a common system input. 3) By standard techniques, determine two system transfer functions, one when the switch is open and the other when the switch is closed. 4) Compensate the transfer functions by classical or root locus techniques and simultaneously minimize ill effects caused by initial conditions.

In the preceding analysis, saturation was assumed to take place in the sensor element only. Actually in many cases, the saturation results in the amplifier or the motor. In order to treat this type of system solely by the above procedure, it would be necessary to limit the sensor output at a level low enough to make the saturation in other parts of the system negligible.

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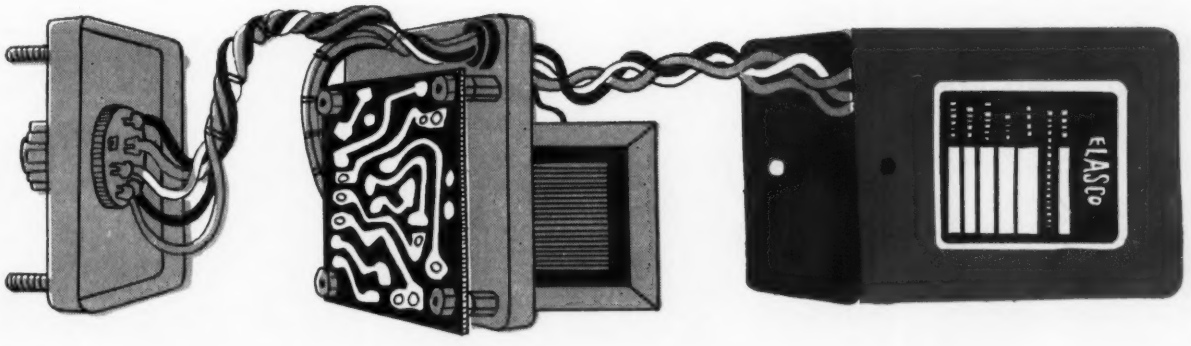
When he opens the case, our engineer will see all the components-capacitors , diodes, even the transformer hopelessly buried in a potted mess . . . shockproof and unfixable. Locating, checking, replacing a burned out component calls for a kind of delicate pottelectomy . . . and all he can do is file the experience and junk the supply.

Sad, sad story? It doesn't have to be. If the power supply is an Elasco transistorized Minisource®, the surgery will be simple, quick and successful. Just as shockproof as the potted source, but completely serviceable, the Minisource® has its components neatly and securely mounted on a printed circuit board — easily accessible for replacement or repair.



COMPLETE SERVICEABILITY? WHO NEEDS IT?
ONE DAY YOU MAY . . . ANYBODY CAN MAKE A MISTAKE,
OR BE DISTRACTED. IN THE MINISOURCE®
COMPLETE SERVICEABILITY COSTS YOU NOTHING.

ELECTRONIC ASSEMBLY COMPANY, INC.

FIVE PRESCOTT STREET, ROXBURY 19, MASSACHUSETTS

CIRCLE 37 ON INQUIRY CARD

STANDARD AND SPECIAL PURPOSE POWER SUPPLIES FO

TRANSISTORIZED AC TO DC ELASCO MINISOURCE® POWER SUPPLIES

FIXED AND SEMI-VARIABLE

ANSISTORIZED

her current capabilities in a smaller ter package . . . greatly improved effi- ces and reliability . . . less heat per watt ut . . . no filament power losses . . . re- ed transformer and rectifier losses . . . warmup time . . . longer life.

MPLETE SERVICEABILITY

components accessible for checking and placement . . . potting has been eliminated a printed circuit board incorporated for mpact packaging.

TICIENT HEAT TRANSFER

complished by mounting the power tran - or on the geometric center of the black dized aluminum housing, which becomes efficient black body radiating heat sink Better heat transfer assures more accu- , stable and long-life performance of all mponents.

LL PROTECTION

ing in the collector of the power transis- protects the supply without affecting lation.

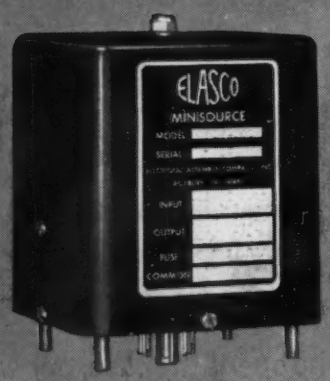
standard Minisource® power supplies are nished with an octal glass to metal header ier terminations available upon request) packaged in a black anodized aluminum nsformer case. There is no extra charge 400 cycles.

CIFICATIONS

LTAGE REGULATED —

ED OR SEMI-VARIABLE * OUTPUT

t Frequency: 60 cps or 400 cps
t Voltage: 105-125 VAC
out Voltage: 4 to 200 VDC
out Current: 50 to 500 ma
lation: Better than 0.5%
le: Less than 0.25%
rity: May be used Floating, Positive, or ative
ew driver adjustment on top of semi- ble units.



FIXED MINISOURCE

MODEL	VOLTAGE	CURRENT	CASE SIZE
M4.5-50	4.5v.	50 ma	B
M4.5-100	4.5v.	100 ma	B
M4.5-250	4.5v.	250 ma	B
M4.5-500	4.5v.	500 ma	B
M6-50	6v.	50 ma	A
M6-100	6v.	100 ma	A
M6-250	6v.	250 ma	A
M6-500	6v.	500 ma	B
M12-50	12v.	50 ma	A
M12-100	12v.	100 ma	A
M12-250	12v.	250 ma	B
M12-500	12v.	500 ma	B
M22-50	22v.	50 ma	A
M22-100	22v.	100 ma	B
M22-250	22v.	250 ma	B
M22-500	22v.	500 ma	B
M25-50	25v.	50 ma	B
M25-100	25v.	100 ma	B
M25-250	25v.	250 ma	B
M25-500	25v.	500 ma	B
M28-50	28v.	50 ma	B
M28-100	28v.	100 ma	B
M28-250	28v.	250 ma	B
M28-500	28v.	500 ma	B
M30-50	30v.	50 ma	B
M30-100	30v.	100 ma	B
M30-250	30v.	250 ma	B
M30-400	30v.	400 ma	B
M50-50	50v.	50 ma	B
M50-100	50v.	100 ma	B
M50-250	50v.	250 ma	C
M100-100	100v.	100 ma	C
M150-100	150v.	100 ma	C
M200-100	200v.	100 ma	C

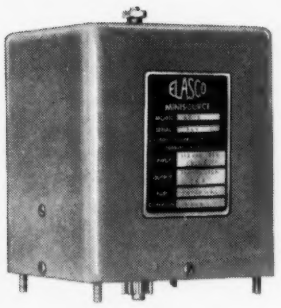
SEMI-VARIABLE MINISOURCE

MODEL	VOLTAGE	CURRENT	CASE
V4-50	3-6v.	50 ma	B
V4-100	3-6v.	100 ma	B
V4-250	3-6v.	250 ma	B
V4-500	3-6v.	500 ma	B
V8-50	5-10v.	50 ma	A
V8-100	5-10v.	100 ma	A
V8-250	5-10v.	250 ma	B
V8-500	5-10v.	500 ma	B
V12-500	10-15v.	500 ma	B
V15-50	10-20v.	50 ma	A
V15-100	10-20v.	100 ma	B
V15-250	10-20v.	250 ma	B
V18-500	15-20v.	500 ma	B
V22-500	20-25v.	500 ma	B
V25-50	20-30v.	50 ma	A
V25-100	20-30v.	100 ma	B
V25-250	20-30v.	250 ma	B
V28-500	25-30v.	500 ma	B
V32-250	30-35v.	250 ma	B
V35-50	30-40v.	50 ma	B
V35-100	30-40v.	100 ma	B
V38-250	35-40v.	250 ma	B
V42-250	40-45v.	250 ma	C
V45-50	40-50v.	50 ma	B
V45-100	40-50v.	100 ma	B
V48-250	45-50v.	250 ma	C
V65-50	60-70v.	50 ma	B
V65-100	60-70v.	100 ma	B
V75-50	70-80v.	50 ma	B
V75-100	70-80v.	100 ma	B

CASE SIZES →

THE SUPPLY YOU REQUIRE IS NOT AMONG THE MODELS LISTED ABOVE, ELASCO WILL BE HAPPY TO BUILD A MINISOURCE® TO
PECIFICATIONS. MULTIPLE MINISOURCE® UNITS MAY BE INCORPORATED INTO A SINGLE PACKAGE SEE MODEL PC-4000 ON INSIDE BACK

lascoelascoelascoelascoelascoelascoelascoelascoelascoelascoelascoe



AC VOLTAGE REGULATORS are small and cool running . . . . . full semi-conductor design . . . and not frequency sensitive. Output voltage is a constant average and may be made variable over a small range. Wave form is not a sine wave.

STANDARD MODELS

Frequency: 55-65 cps
Input Voltage: 105-125 VAC
Regulation ±1%, half load to full load
Dimensions: 4¾" w x 5¾" h x 5" d
Meets MIL SPEC. MIL-E-5282A

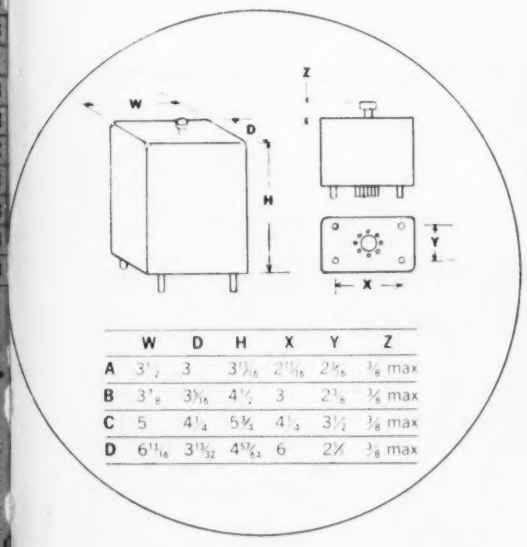
MODEL	Output VOLTAGE	CURRENT
AR-1	115 VAC,	1 amp.
AR-2	6.3 VAC,	10 amps.
AR-3	12.6 VAC,	5 amps.

DC-DC MINIATURIZED CONVERTERS. ELASCO has designed and manufactured DC-DC converters — standard, and special purpose units to customers' specifications.

Minisource converters are completely transistorized and have no moving parts, such as make and break contacts; consequently, they provide longer life — maintenance free, excellent shock and vibration characteristics, improved operating ratios and efficiency — in a smaller, lighter package. All supplies are short circuit proof.

STANDARD MODELS (unregulated)

MODEL	INPUT VOLTAGE	OUTPUT VOLTAGE	CURRENT	CASE SIZE
D125-100	12 VDC	125 VDC	100 ma	A
D150-100	12 VDC	150 VDC	100 ma	A
D250-100	12 VDC	250 VDC	100 ma	A
D300-100	12 VDC	300 VDC	100 ma	B



	W	D	H	X	Y	Z
A	3 1/2	3	3 11/16	2 11/16	2 1/16	3/8 max
B	3 7/8	3 5/16	4 1/2	3	2 3/8	3/8 max
C	5	4 1/4	5 1/4	4 1/4	3 1/2	3/8 max
D	6 11/16	3 13/32	4 57/64	6	2 1/4	3/8 max

SPECIAL UNITS

Example: Power supply for commercial pleasure craft marine radar system.

Inputs: 12 VDC, 9.6 amps., 115 watts . . . . . , or
32 VDC, 3.6 amps., 115 watts

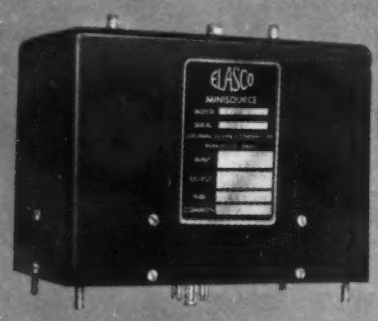
Outputs: +1500 VDC, 1 ma
−1500 VDC, 1 ma
+300 VDC, 225 ma
+150 VDC, 75 ma
−150 VDC, 4 ma
6.3 VAC, 1 amp

All outputs unregulated except for −150 VDC, 4 ma which was regulated to 2%.

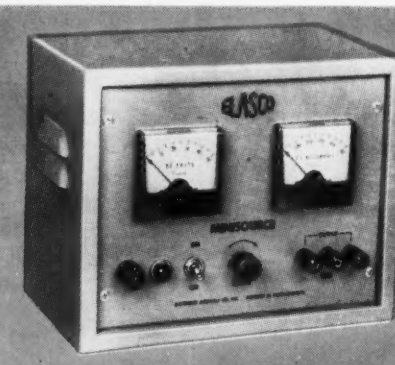
Efficiency: 77% Size: 5" x 7" x 6"

A prototype was delivered in less than 30 days after receipt of order

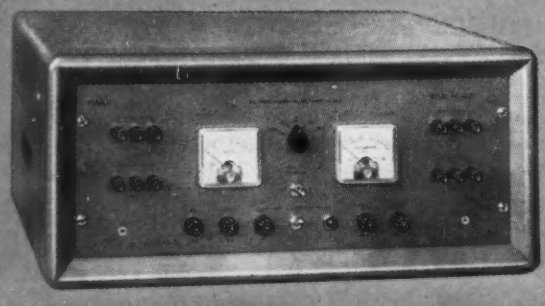
RACK AND CABINET MODEL POWER SUPPLIES



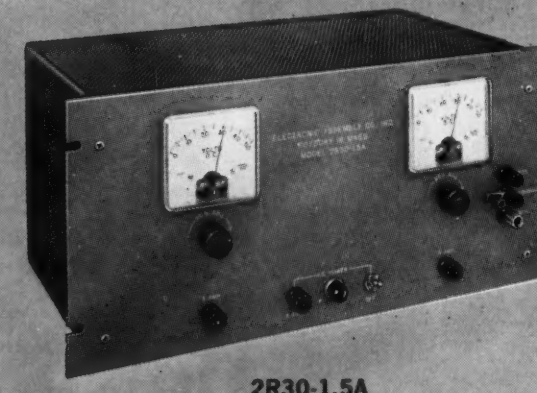
*2V70-50



FR30-1A

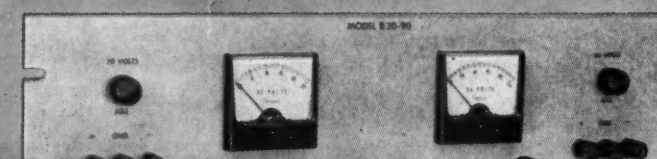


PC-4000



2R30-1.5A

ELASCO can package power supplies in any way the customer may desire (within reason), and to comply with military requirements. Specifications and illustrations of several rack and cabinet models are shown on this page. Units, once specials, are now available as standard models.



R20-90

MODEL	INPUT	OUTPUT	CASE SIZE
2V70-50	115VAC60 cps	+70 volts @ 50 ma • −70 volts @ 50 ma	D
2R30-1.5A	115VAC60 cps	+0 to 30 volts @ 1.5A • −0 to 30 volts @ 1.5A	Rack mounted
PC-4000	115VAC60 cps	+6V @ 500 ma • +10V @ 500 ma • 10V @ 500 ma • 29.5V @ 500 ma	Laboratory Power Case
PC-4001	115VAC60 cps	3-6V @ 250 ma • 15-25V @ 500ma • 15-25V @ 1A • 10-20V @ 2A	Rack mounted
PC-3001	115VAC60 cps	+6V @ 2A • −6V @ 1A • −18V • 2A	Rack mounted
2E30-100	115VAC400 cps	+30VDC @ 100 ma • −30VDC @ 100 ma	MIL Spec Module
RM150-500	115VAC60 cps	150V @ 500 ma	Rack mounted
E60-175	115VAC400 cps	60V @ 175 ma	MIL Spec "B"
M115-1A	115VAC60 cps	115V @ 1A	Small Power Case
FR30-1A	115VAC60 cps	115V @ 1A	Small Power Case

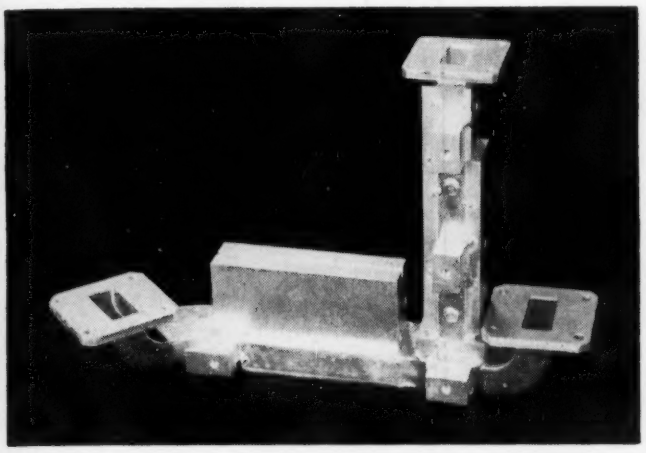


Figure 1.

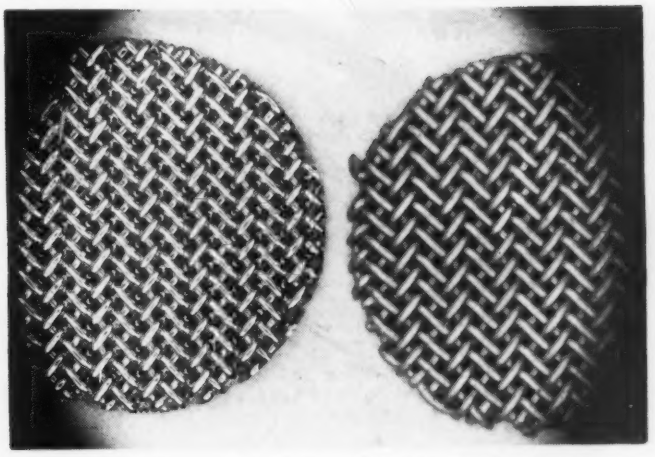


Figure 2. Wire mesh filter. Electropolished (left). As formed (right).

CHEMICAL AND ELECTRO-CHEMICAL POLISHING

Time-Saving Technique Solves Difficult Problem

R. L. Borenstein
Air Arm Div., Westinghouse Electric
Baltimore, Md.

During the past few years both chemical and electropolishing procedures have received great impetus in use as replacements for buffing in the decorative finishing of metals. Very recently these procedures have been applied to removal of burrs from machined metal parts. The use of each of these processes in the solution of particularly difficult problems is discussed here.

CHEMICAL POLISHING

The electrical performance of certain components in microwave wave guide systems is so critical that it is not possible to obtain consistently reproducible results on successive parts using conventional fabrication techniques. One such part, a continuous wave filter, is fabricated from aluminum alloy. Machine milled sections and extruded waveguide are joined by a dip brazing process. The complete assembly is then processed to the required electrical performance by immersion in a chemical polishing solution. The filter is processed as follows:

- Aluminum alloy plate is machine milled to form the center section of cavity assembly.
- Side plates are assembled by dip brazing.
- Cavity assembly is chemically polished in MacDermid Aluminum Bright Dip #2 maintained at 180F for 1 to 2 minutes. This smooths the fillets formed in dip brazing and precleans assembly for next operation.
- Shaped waveguide, mounting flanges and cavity assembly are mounted into a fixture, tack welded together and electrically tested.
- If electrical performance is satisfactory, the assembly is joined by dip brazing.
- If performance is unsatisfactory, minute changes are made by further chemical polishing or by hand adjustment until performance is within specification. Filter assemblies are not dip brazed until they exhibit correct electrical performance.

After the flux has been removed from the assembly, it is again tested for electrical performance, since the high heat necessary for brazing effects minute changes in location and dimensions of the individual sections.

If performance has changed, the complete assembly is chemically polished for two minutes and retested (Fig 1). This procedure is repeated until a satisfactory filter assembly is produced.

ELECTROPOLISHING

All parts in precision hydraulic systems which are exposed to fluid flow must be deburred of projections which may break off and either restrict fluid passages or restrain motion of moving parts. It has been standard procedure to remove these projections by the use of hand manicuring, dental power tools or barrel tumbling. In recent years, the characteristic ability of electropolishing solutions to effect leveling on metal surfaces has been put into use for burr removal.

In one case, a small stainless steel filter was deburred of objectionable projections by electropolishing technique. These filters are approximately ⅜ inch diameter and are composed of one layer of two meshes of stainless steel screening. After punching, very fine feather burrs present on the sheared edges of the screening were polished off as follows:

- Alkaline preclean and water rinse.
- Electropolish in Battelle Stainless Steel Electropolish at 180F for 10 seconds at 1 ampere/filter.
- Water rinse and dry.

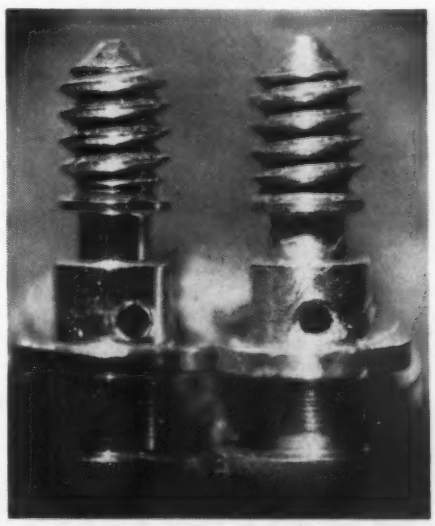
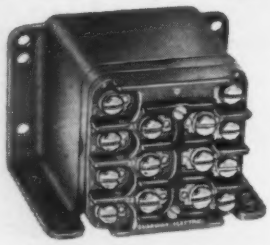
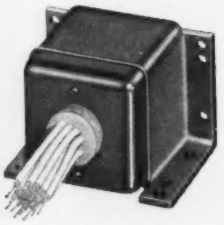


Figure 3. Hydraulic nozzle. Electropolished nozzle on left. Nozzle as machined on right.

EVERYTHING UNDER CONTROL

FEATURING
GUARDIAN®
MINIMUM CURRENT RELAYS
Series 3005





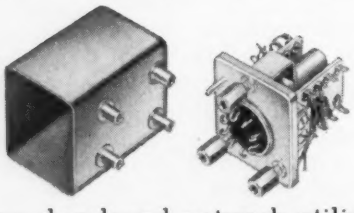
This Guardian rotary type Series 3005 relay meets overload rupture, vibration and *minimum current* requirements of MIL-R-6106-C. Operates 4 P.D.T., at 10 amperes—has vibration resistance of 15 G's to 1000 cycles *plus* 10 G's from 1000 to 2000 cycles—applicable for temperature ranges of −65° C. to +120° C. Standard coil voltage of 24 to 28 volts DC. Also available with rectification network for AC operation up to 400 cps.

SCREW TYPE . . .
Hermetically sealed. Available with standard screw type terminals.

POTTED TYPE . . .
Available with potted type leads to decrease external dielectric problems.

★ ★ ★ ★ ★ ★ ★ ★ ★ ★ ★

GUARDIAN
Close Differential
RELAYS



Aircraft Catalog "D"

A Guardian developed network utilizing static devices in conjunction with the Series 1005 Relay creates the ultimate in *close differential* requirements without using sundry mechanical devices. This *close differential* relay has D.P.D.T. contacts rated at 3 amperes. Operating voltage is 24 ±2 volts, release voltage is 22 ±2 volts. Maximum differential between attract and release is 2 volts. Applicable for temperature ranges of −65° C. to +125° C.

Visit Guardian's Booth at A.E.S. Show—Los Angeles

Write on your company letterhead for catalog "D"

GUARDIAN ELECTRIC
MANUFACTURING COMPANY
1641-L W. WALNUT STREET, • CHICAGO 12, ILLINOIS
CIRCLE 38 ON INQUIRY CARD

This procedure does not cause stress corrosion cracking, effectively removes all projections visible under 40 power magnification and improves the appearance of the wire mesh surfaces (Fig 2). As there are no extremely critical dimensions on this part the electropolishing cycle was selected to give satisfactory deburring in the shortest time.

Another application was the deburring and removal of sharp corners from the threaded portions of a stainless steel nozzle. This operation was necessary to minimize burr formation and chipping when the nozzle was assembled. The procedure for this was as follows:

- Alkaline preclean and water rinse.
- Electropolish in Battelle Stainless Steel Electropolish at 170F for 15 seconds at 4 amperes per nozzle.
- Water rinse and dry.

This procedure smoothed both the crown and root of the screw threads and rounded all sharp corners (Fig 3). Metal removal through this cycle was 0.00015 inch per surface, which was satisfactory to maintain the Class III fit on the threads.

Chemical and electropolishing techniques have a definite use in the manufacture of precision metal parts, both for milling and for burr removal. When properly applied to burr removal, these techniques can reduce, considerably, the time spent in manual or other operations.

For more information on these techniques:
Circle No. 76 on Inquiry Card

WORTH FILING

Design Guide for RFI Shielding

Comprehensive technical data and product information on RFI gasketing help designers solve specific shielding problems. Fully illustrated, the guide contains technical data and practical information with problem outline sheets.

Source: Technical Wire Products, Inc.
Springfield, N. J.

For your copy: Circle No. 179 on Inquiry Card

WORTH FILING

Slide Rule Calculator Predicts Room Noise Rise

Fan noise calculator combines several acoustical formulas to give accurate predictions of room noise levels resulting from fan additions. Calculator covers rooms of various sizes and with various degrees of acoustical treatment. Calculators are available at no charge when requested on your company letterhead.

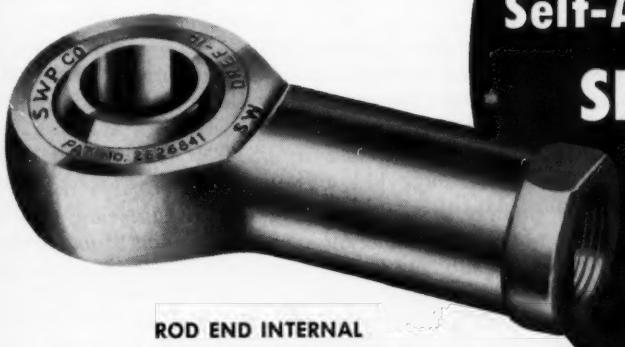
Source: Robbins & Myers, Inc.
Propellair Div.
Springfield, Ohio

"LFN" SERIES

"Dyflon"®

Self-Aligning and Self-Lubricating SPHERICAL BEARINGS

Combine "Monoball"® Engineering Advantages with Life-Time Lubrication



ROD END INTERNAL THREAD TYPE "DREF" SERIES

Design engineers in many industries are specifying new "DYFLON"® SELF-ALIGNING and SELF-LUBRICATING SPHERICAL BEARINGS for these 5 major reasons:

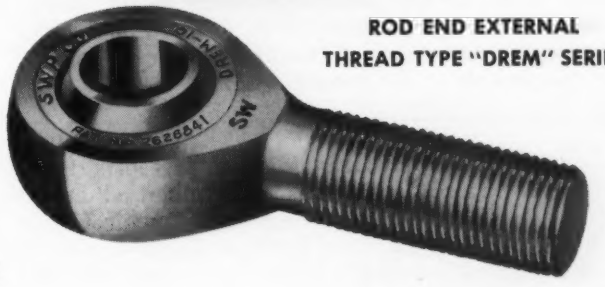
1. LOWER COEFFICIENT OF FRICTION ... ideal where lubrication is impossible or undesirable.

2. WITHSTAND EXTREME VIBRATION ... perfect performance under shock load conditions.

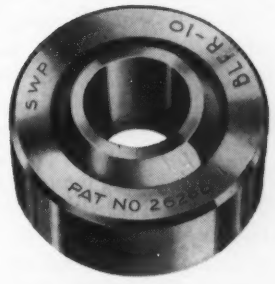
3. WILL NOT "COLD-FLOW" ... even under extreme load conditions.

4. IMPERVIOUS TO KNOWN CHEMICAL SOLVENTS ... eliminates corrosion problems.

5. FAIL SAFE ... due to "Monoball"® design.



ROD END EXTERNAL THREAD TYPE "DREM" SERIES



"LF" SERIES

In addition, due to their two-piece "MONOBALL"® design and plastic alloy insert, "DYFLON"® bearings have a long cycle life. Alignment and installation problems are minimized. Oil-free for life means lowest possible maintenance costs.

Available in a variety of plain or rod end types. Bore sizes to 3.000". Materials include stainless steel, plastic alloys and chrome alloy steels. Ultimate static loads to 500,000 lbs.

Engineered to the same high standards as Southwest's popular "MONOBALL"® Self-Aligning Bearings.

SOUTHWEST "DYFLON"® "Monoball"® bearings can solve your difficult alignment and installation problems. Request Engineering manual No. 551.

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RELIABLE PRODUCTS

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1705 SO. MOUNTAIN AVE. • MONROVIA, CALIF. • PHONE: MURRAY 1-9616

CIRCLE 39 ON INQUIRY CARD

MANAGEMENT

STAFF COLUMNIST

Hyman Olken

Lawrence Radiation Laboratory
University of California
Livermore, California

MENTAL PROCESS OF INVENTING—

The Trial-and-Error Combination of Mental Images

Our first column in this series (Feb. 1959) pointed out the need and feasibility of training to develop the inventive ability of engineers. A common difficulty in discussions on the creative activity of engineers and inventors has been that the words commonly used in these discussions often have different meanings to different people, so our second column (September) provided a "clearing of the air" by defining these terms so that the author and reader will interpret them alike.

The aim of this series is to point out how the engineer of average inventive ability can develop greater proficiency at inventing, and to achieve this by the self instruction process. This article and the next few in this series will therefore point out the basic components of the mental process of inventing; and these will be followed by a group which provide pointers on developing proficiency in each of the components of the process.

From self-observing inventors and from psychologists we learn that the idea combinations are synthesized in the human mind by a process of trial-and-error combination of mental images. First, the mind forms an image of the desired invention and second, it brings up images from the memory and arranges them in different combinations. Each combination is tested by matching it against the desired pattern and those which do not fit are discarded. This process is continued until it becomes a habit at which time it goes on unconsciously. Whether unconsciously or deliberately, the process goes on until a solution is reached which matches the mental picture of the desired method, machine or process. The mental image of the new idea combination is then translated into concrete form, by blueprints, test models or pilot plants, which can be tested and improved until a practical embodiment is reached.

In the book, **PSYCHOLOGY OF THE INVENTOR,** J. Rossman quotes a number of inventors and psychologists on this process. On page 60 one keenly observing inventor says:

Initially "*. . . there is direct contact with and observation of the process, apparatus or product desired to be improved . . . this contact resulting in sharp mental pictures . . . It is with these sharp images that a number of new pictures are synthesized and reconstructed just as a child builds up a number of buildings with blocks.*"

Another observant inventor explains the process in more detail on page 77:

"The actual inventing becomes more or less a problem in mental mathematics–the addition and subtraction of materials, energy, motion . . . If a peculiar movement is required, all the known movements are brought to the mental picture and, one by one, are added or subtracted which may result in a combination of old ideas and new . . .

"Up to this time it is purely a mental picture . . . a mental painting . . . I call it . . .

"When this mental painting is complete, you then begin putting your idea into practice, either by constructing a model or a real picture."

On page 82 we find the whole process aptly summarized by a psychologist:

"*. . . the interesting aspect of this inventive process is that most of the efforts are first made mentally. The inventor manipulates the symbols of his past experience mentally, and only after a satisfactory solution is obtained by mental trial-and-error behavior does he actually attempt to satisfy the need.*"

Though invention resolves down to the simple mental procedure of trial-and-error combination of mental images, one should not get the notion that this procedure is either done quickly or is easy to accomplish.

Another inventor, quoted in **PSYCHOLOGY OF THE INVENTOR** on Page 111, tells us:

"The process of inventing begins with guessing, but a guess is not an invention. As soon as the inventor makes his first guess he subjects it to a shifting process in which the guess has to run the gauntlet of all the pertinent facts he can think of. The chances are a million to one that the first guess he discarded within the fraction of a second and another takes its place. A thousand to one the second guess follows the first, but a little more slowly, and a third takes its place on the firing line. Usually this lasts a little longer, but it is a hundred to one that this also goes overboard and a fourth takes its place. A skilled inventor is liable to pass a hundred guesses in review in less time than it would take to explain one of them."

This process may go on for days. If the current solution is not reached after a while, the process may be dropped to be resumed weeks, months or years later.

Skill in creating and in manipulation of mental images is the basic requirement of a good inventor, particularly in these days of highly technical and complex inventions. Cyclotrons, computers and color television systems are too costly to be built, torn down, changed and built over and over again. Therefore, the modern inventor must be able to readily create mental images of these devices, to quickly visualize changes in them and to test out such changes by mental manipulation of those images.

BREAK THE PROBLEM INTO PARTS

Another characteristic of the creative mental process is that of breaking down the major invention problem into small parts and attacking them one at a time. For example, in so simple an invention as that of printing by movable type, Gutenberg had several parts of the problem to solve: (a) how to produce the individual characters; (b) how to arrange them at the desired locations on the page; and (c) how to transfer the entire (full page) image onto paper.

In J. M. Montmassan's **INVENTION and the UNCONSCIOUS,** Pages 171 to 176, Gutenberg by observing his own mind in action during the inventing process gives a classic account of peacemeal attack procedure and the solutions of small parts of the invention problem. First he states the overall invention problem:

"For a month my head has been working; a Minerva, fully armed, must issue from my brain . . . I wish to write by a single application of my hand . . . in a single instant . . . everything that can be put onto a large sheet of paper . . ." Then he arrives at his solution to the first part of the problem–how to produce the individual characters–as follows: *"First, the relief in steel, the punch carrying at its extremity the engraved letter. Then the mold obtained by*

driving the punch into the copper. It is the mother of the letters, the matrix; then comes the mold in two parts which interlock. . ." Into this mold he pours the hot lead. "*The molten metal is thrown quickly down from above while the shock given to the mold drives the molten metal into the matrix . . . You open the mold and take out a small model in lead of the steel punch . . . So we have the letters, sisters like to one another and like the original punch.*"

To get the letters arranged at the appropriate place on the printing plate, he takes advantage of the fact that, as individual letters, they are movable.

"*The letters are moveable. The mobility of the letters. . . is the treasure which I have been searching for along unknown roads. With these letters and with the blanks which give separation, I compose words.*"

Gutenberg then attacks the remaining part of the problem –How to transfer the full-page image into the paper sheet. "*You have seen, as I have, playing cards and the pictures of Saints . . . these cards and pictures are engraved on small pieces of wood, and below the pictures there are words and entire lines also engraved . . . A thick ink is applied to the engraving; upon this a leaf of paper, slightly damp, is placed; then this wood, this ink, this paper is rubbed and rubbed until the back of the paper is polished. The paper is then taken off and you see on it the picture just as if the design had been traced upon it, and the words as if they had been written; the ink applied to the engraving has become attached to the paper . . .*"

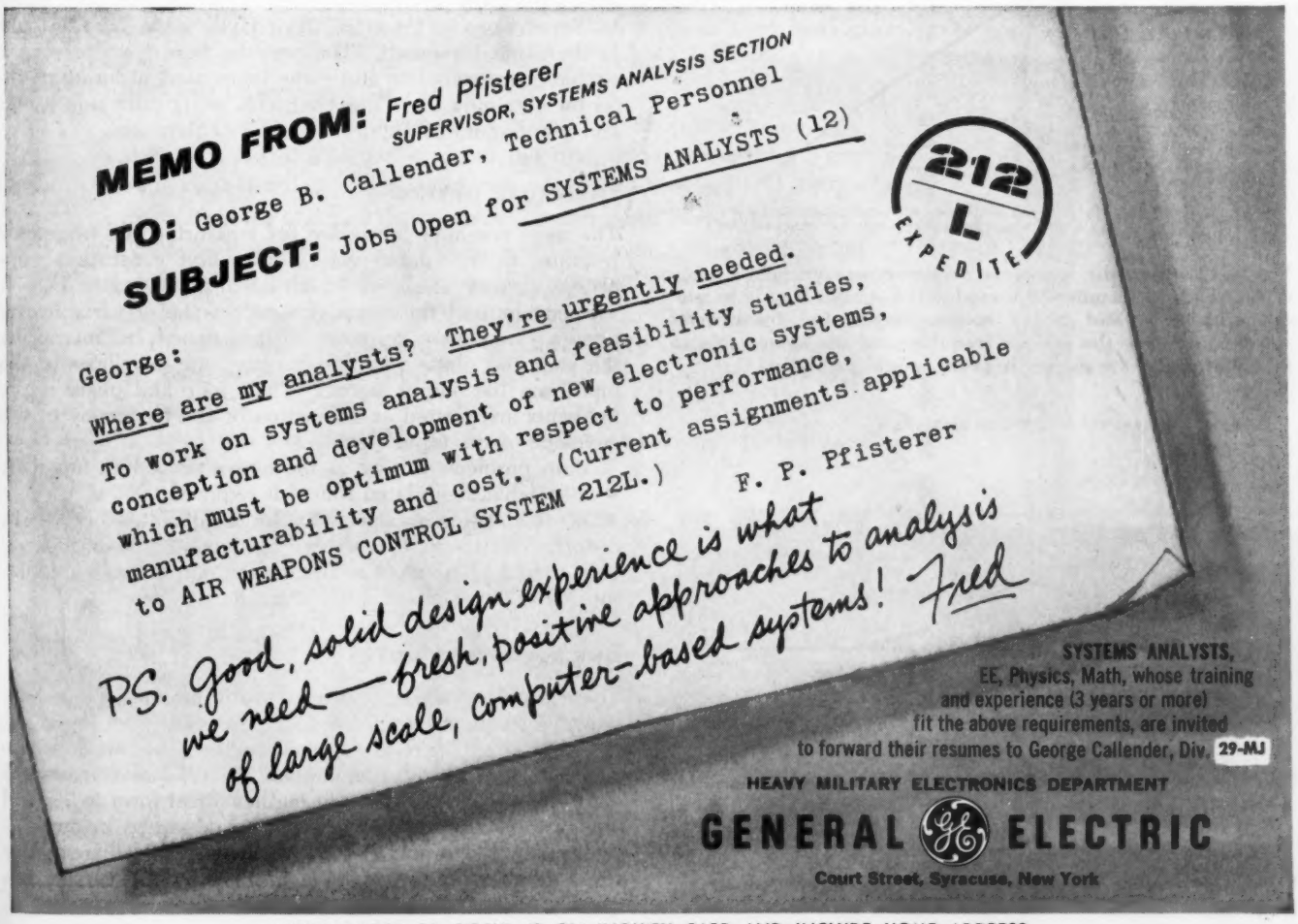
In other words, covering the type with ink and then pressing it onto the paper sheet will transfer the image onto the paper; but the rubbing process is a drawback. It should be possible to transfer the entire image—produce the complete impression—at one stroke. He solves this problem by the screw press, which he arrives at as follows: "*When you apply to the vellum or paper the seal of your community, everything has been said, everything is there. Do you not see that you can repeat as many times as necessary the seal covered with signs and characters? . . .*" "*I took part in the wine harvest. I watched the wine flowing and, going back from the effect to the cause, I studied the power of this press, which nothing can resist.*"

In short, he could transfer the ink of the page full of type onto a paper sheet—just as a seal embosses all its signs and characters onto the paper—at one stroke. But the stroke must be powerful enough to cause the ink to transfer to the sheet. Through the screw press he could make the impression stroke powerful enough to do this.

Thus, Mr. Gutenberg illustrates the fact that the human mind does not jump in one leap to the ultimate solution of a major invention problem. Rather, it first attacks one part of the complex invention problem and creates a small invention to solve the part. Then the mind chips off another small part of the major problem and creates another invention to solve it. This piecemeal attack and solution of small parts of the major invention problem continues until the entire major invention problem is solved. Thus each major invention is accomplished by a succession of small inventions made separately.

One must remember, however, that the size of the parts of the complex problem with which a person can cope is not the same for all individuals. Some can cope with very large parts and for others the part must be very small.

According to Helen E. Durkin's **TRIAL AND ERROR, GRADUAL ANALYSIS AND SUDDEN REORGANIZATION** (*Archives of Psychology, No. 210, May 1937*), Pages 5-85, psychologists call the size of the part of the problem with which a person can cope his "Apprehension Span", which experimental efforts are trying to measure.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TO: George B. Callender, Technical Personnel
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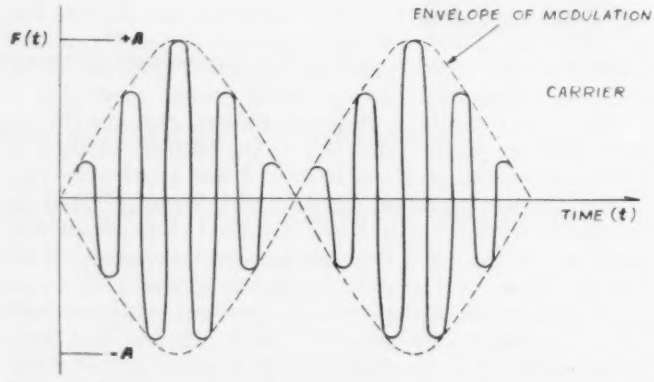

Fig. 1—Usual method for measuring frequency response to modulated waves is to generate a suppressed carrier amplitude modulated signal and measure the gain and phase variation between the envelopes of the input and output signals. These measurements are then plotted as a function of the frequency of the input signal envelope.

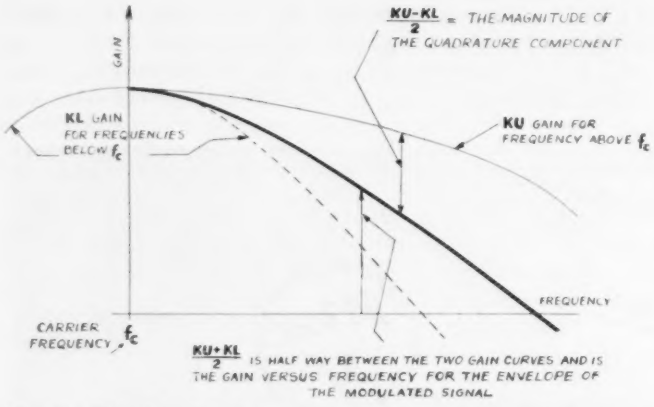
GAIN
KU-KL / 2 = THE MAGNITUDE OF THE QUADRATURE COMPONENT
KL GAIN FOR FREQUENCIES BELOW fc
KU GAIN FOR FREQUENCY ABOVE fc
FREQUENCY
CARRIER FREQUENCY fc
KU+KL / 2 IS HALF WAY BETWEEN THE TWO GAIN CURVES AND IS THE GAIN VERSUS FREQUENCY FOR THE ENVELOPE OF THE MODULATED SIGNAL

Fig. 2—Plotting the sine wave response measurements properly directly determines the modulated signal. Key is to plot the amp'itude and phase measurements for frequencies above and below the carrier frequency on the same scale so that the carrier frequency is at the origin as above.

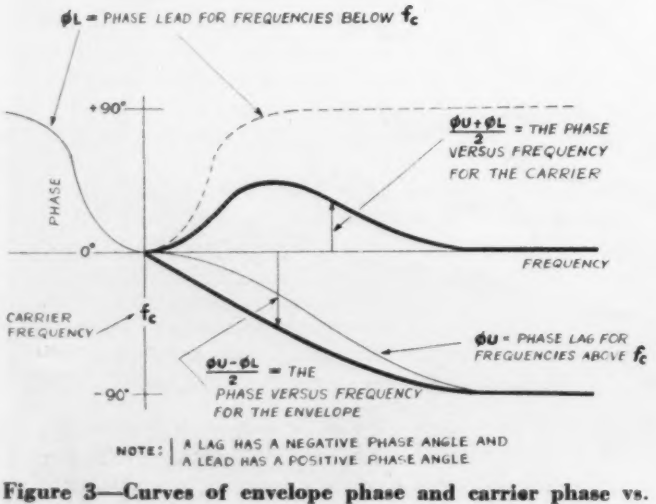
φL = PHASE LEAD FOR FREQUENCIES BELOW fc
+90°
φU+φL / 2 = THE PHASE VERSUS FREQUENCY FOR THE CARRIER
PHASE
0°
FREQUENCY
CARRIER FREQUENCY fc
φU = PHASE LAG FOR FREQUENCIES ABOVE fc
φU-φL / 2 = THE PHASE VERSUS FREQUENCY FOR THE ENVELOPE
-90°
NOTE: A LAG HAS A NEGATIVE PHASE ANGLE AND A LEAD HAS A POSITIVE PHASE ANGLE

Figure 3—Curves of envelope phase and carrier phase vs. frequency.

Predicting Response to Modulated Inputs from Response to Sine Wave Inputs

by Martin Glasberg

Research Division, United Shoe Machinery Corp.

Here is a simple method for plotting a component's frequency response to sine waves to determine its frequency response to suppressed carrier modulated signals. Measuring the initial sine wave response data is simple and requires no special equipment. This method also determines the carrier phase shift with frequency and the magnitude of the quadrature component.

In analyzing an a-c servomechanism, the general procedure is to measure the frequency response of each component to a modulated input. Many methods for these measurements exist with many instruments, such as the "Servoscope" made by Servo Corp. of America, New Hyde Park, N. Y., to aid in these measurements. The purpose here is to present a simple, more complete and many times more accurate method for obtaining these measurements using pure sine waves and a minimum of regular laboratory equipment.

THE USUAL METHOD

The most common procedure for measuring the frequency response to modulated waves is to first generate a suppressed carrier amplitude modulated signal, as in Fig. 1. The envelope of this signal is a sine wave of variable frequency; frequency response is determined by measuring the gain and phase variation between the envelopes of the input and the output signals. These gain and phase measurements are plotted as a function of the frequency of the envelope of the input signal.

Main problems arising in the above procedure are that:

- a variable, modulated source is required;
- phase shift measurements are quite difficult, especially if: distortion exists in the system component under observation; carrier phase shift occurs; or the output has a quadrature (90 degree phase shift) signal component

SINE WAVE METHOD

These problems are not encountered in measuring the component's frequency response to a pure sine wave input signal. The question then is: *how can the response to a suppressed carrier modulated signal be predicted from this data?* The answer is given in mathematical form in Table I and in the simple graphical procedure outlined below.

The key to the graphical solution is to plot all frequency response measurements above and below the carrier frequency on the same scale, as in Figs. 2 and 3. In Fig. 2,

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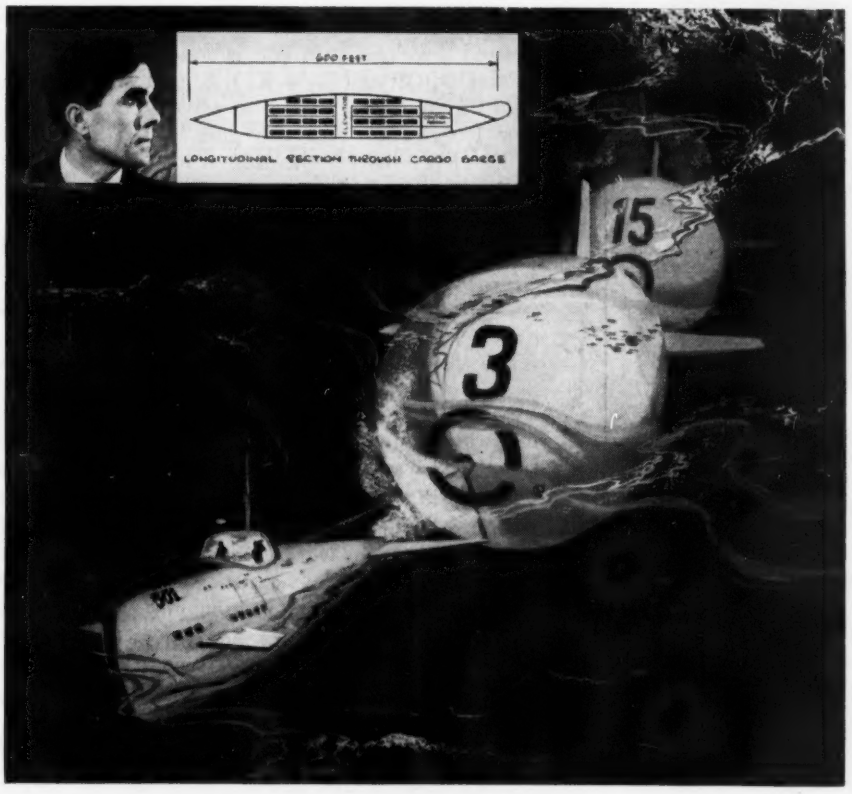

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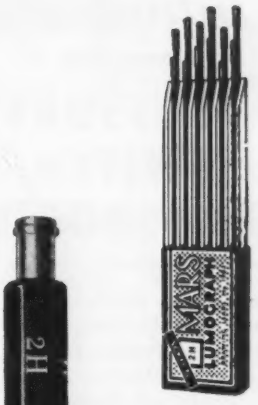

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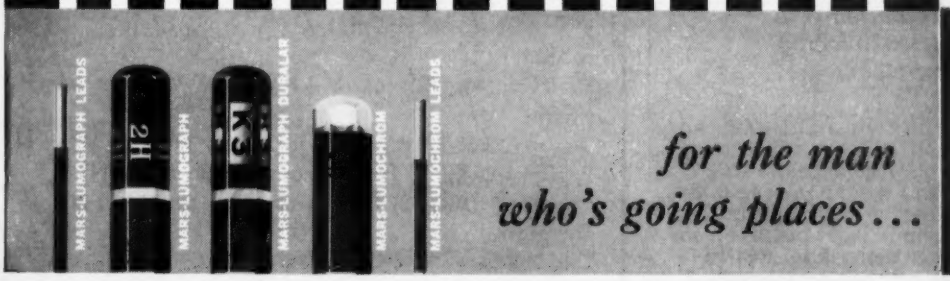

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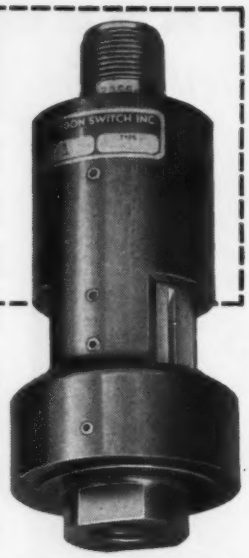

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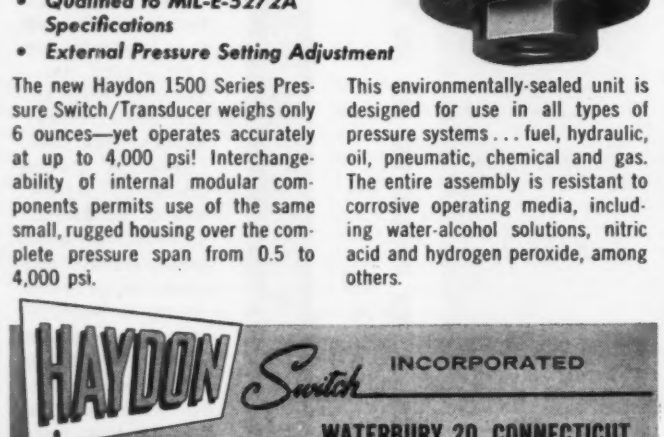

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the desired envelope gain versus frequency curve is shown heavy and equal to $(K_U + K_L)/2$, or exactly the average between the gain (K_U) for sine wave frequencies above f_c (carrier frequency) and the gain (K_L) for frequencies below f_c. $(K_U - K_L)/2$ also shown in Fig. 2 is the magnitude of the quadrature component in the modulated output signal.

In Fig. 3, the desired envelope phase versus frequency curve is shown heavy and equal to $(\Phi_U - \Phi_L)/2$, or exactly

TABLE I

The two frequency components of the "beat wave", F(t) of Fig. 1 are $(f_c + f_m)$, the upper side band; and $(f_c - f_m)$, the lower side band. If this wave passes through an arbitrary instrument, the effect on the frequency components will be the frequency response. To solve for this effect, let's assume the following characteristics for the arbitrary instrument:

K_U = component's gain for sine waves at frequencies above carrier frequency.

K_L = component's gain for sine waves at frequencies below carrier frequency.

Φ_U = component's phase shift of a sine wave at frequencies above carrier frequency.

Φ_L = component's phase shift of a sine wave at frequencies below carrier frequency.

If the input is a suppressed carrier modulated wave, it can be written as:

$$F_{in}(t) = A \cos 2\pi f_m t \cos 2\pi f_c t$$

where

f_c = carrier frequency

f_m = modulation or envelope frequency

or as:

$$F_{in}(t) = (A/2) \cos 2\pi(f_c - f_m)\ t + (A/2) \cos 2\pi(f_c + f_m)t$$

The output signal will be the input acted on by the component's frequency characteristics. Consequently:

$$F_{out}(t) = (AK_L/2) \cos [2\pi(f_c - f_m)t + \Phi_L] + (AK_U/2) \cos [2\pi(f_c + f_m)t + \Phi_U]$$

then:

$$F_{out}(t) = (AK_U/2) \cos \{ [2\pi f_c t + (\Phi_L + \Phi_L)/2] + [2\pi f_m t + (\Phi_U - \Phi_L)/2] \} + (AK_L/2) \cos \{ [2\pi f_c t + (\Phi_U + \Phi_L)/2] - [2\pi f_m t + (\Phi_U - \Phi_L)/2] \}$$

Let $M = 2\pi f_c t + (\Phi_U + \Phi_L)/2$

$N = 2\pi f_m t + (\Phi_U - \Phi_L)/2$

so that:

$$F_{out}(t) = (AK_U/2) \cos (M+N) + (AK_L/2) \cos (M-N)$$

where:

$$\cos (M \pm N) = \cos M \cos N \pm \sin M \sin N$$

$$F_{out}(t) = (AK_U/2) [\cos M \cos N - \sin M \sin N] + (AK_L/2) [\cos M \cos N + \sin M \sin N]$$

Therefore:

This yields:

$$F_{out}(t) = [A(K_U + K_L)]/2 \{ (\cos M \cos N) + \{ [A(K_L - K_U)] /2 \} (\sin M \sin N)$$

one-half the difference between the phase shift (Φ_U) at frequencies above f_c and the phase shift $(\Phi_U + \Phi_L)/2$ also shown in Fig. 3 is the phase shift of the carrier versus frequency. Note that a lag has a negative phase angle and that a lead has a positive phase angle.

It should be pointed out that the method described here is not applicable to components that have an inherent dependence of a modulated signal, such as two-phase motors, synchros or drag cup tachometers. In most of these cases, the modulated frequency (the frequency response) can be ascertained from the transient response. The simplest method is to record the unsaturated transient and match this record against a reference transient. For example, the velocity transient of a two-phase motor will resemble a first order rise where the time constant is the inertia divided by the viscous damping coefficient. The resulting frequency response would then be flat up to the break frequency which is one over the time constant. At frequencies greater than the break frequency the amplitude would be attenuated by 20 decibels per decade. The phase on the other hand would decrease to 45° of lag at the break frequency. From the break frequency to higher frequencies the phase would lag to 90°. The complete frequency response of the two-phase motor would then look like an ideal integration in series with the velocity frequency response discussed above.

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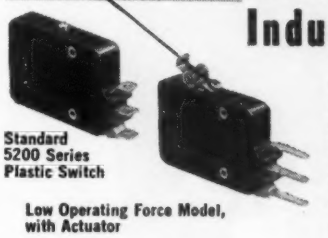

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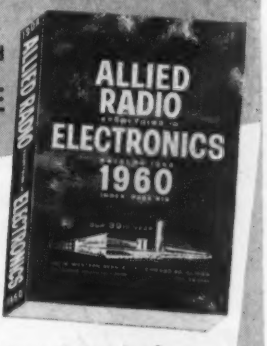

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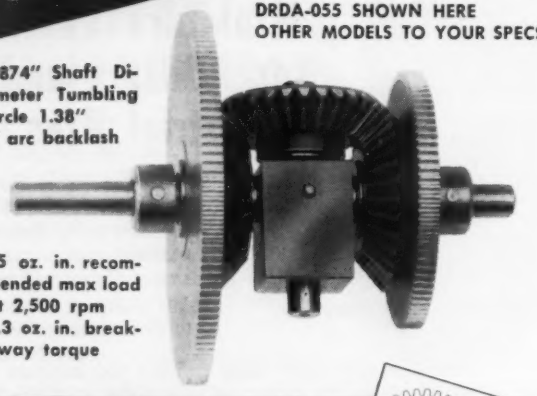

75 oz. in. recommended max load at 2,500 rpm
0.3 oz. in. breakaway torque

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PRECISION **magnetic clutches**

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featuring:

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HIGH CAPACITY . . . up to 80 oz. in. ALL combinations of CROWN TOOTH and FRICTION COUPLINGS and BRAKES.

available from stock
in the following models:

Double-Ended—Input and output on opposite ends.
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WORTH FILING

Hydraulic Controls

Twenty new hydraulic system control units for aircraft and missile operations are presented in a survey bulletin divided into five areas—shear seal valves, hydraulic system components, hydraulic selector valves, poppet relief valves, and shut-off valves. Some of the special illustrated units featured are: an auto-pitch actuator, with an electronic mechanism sensing incipient stall; a stainless steel high pressure, helium relief valve, a solenoid pilot-actuated sleeve selector valve, and a dual solenoid, pilot-actuated spool valve.

Source: Whittaker Controls, Div. of Telecomputing Corp.
Los Angeles, California
For your copy: Circle No. 202 on Inquiry Card

Switching Systems

Six page brochure describes an advanced method of static control through the use of solid state power/logic switching systems. It contains photographs, diagrams and charts outlining the structure of a typical system and provides a functional description of its make-up. Included are details on the magnetic amplifier device used to perform digital computation, switching and power amplification in a single operation. Schematics indicate the connections employed for the principle used to replace electromechanical relays in complex control systems.

Source: Magnetic Amplifiers, Inc.
New York, New York
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Source: Bodine Electric Co.
Chicago, Illinois
For your copy: Circle No. 216 on Inquiry Card

Meters

20-page meter catalog describes three separate products: expanded scale a-c and d-c voltmeters, expanded scale frequency meters, and linear scale ammeters. Each is presented individually, and detailed from primer-like operating principles through complete specifications. Various meter case styles and sizes are illustrated.

Source: Helipot, Div. of Beckman Instruments Inc.
Fullerton, California
For your copy: Circle No. 210 on Inquiry Card

Servovalves

Bulletin describing operation and performance characteristics of a new series of industrial servovalves includes functional schematic, performance curves, and valve specifications as well as installation and overall dimensions.

Source: Moog Servocontrols, Inc.
East Aurora, New York
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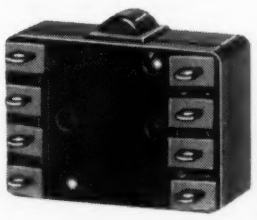
- **quality engineered and designed to meet human factors**
- **over 60,000 switch and actuator variations available**
- **adaptations can be made to fit your requirements**

four circuit? HERE THEY ARE...

double pole



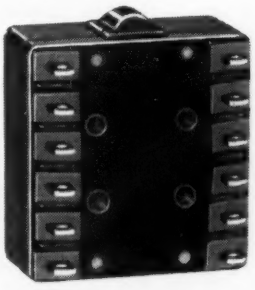
actual size

D series
DPDT, 4 CKT.

L.W.H. 1¼" x ½" x ⅞"
Elec. Rating: 15 amps @ 125/250 V.A.C.
15 amps Res. @ 30 V.D.C.
10 amps Ind. @ 30 V.D.C.
Operating Force 23 to 33 oz.
Amb. Temp. −100 to +375° F.
Termination D4 series—end solder
D8 series—side solder
Available in simultaneous, non-simultaneous and reset models. Models available with Military and U.L. approval. Write for details.

six circuit? THESE TOO...

triple pole



actual size

K series
TPDT, 6 CKT.

L.W.H. 1¼" x .491" x 1-5/16"
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K3 series—side solder
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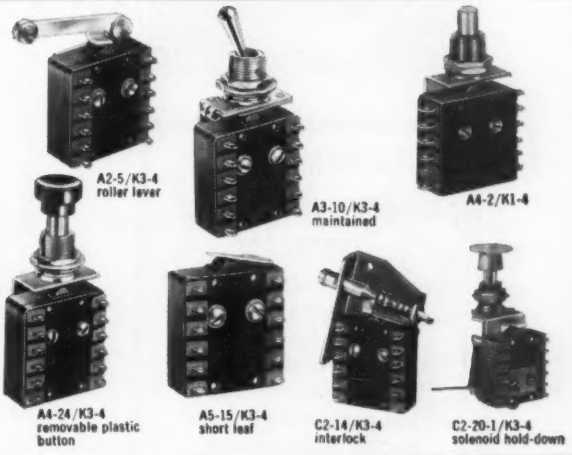

eight circuit? YES...

multi-pole combination actuator assemblies

Any basic switch can be adapted to multi-pole assemblies. Send us your requirements.

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A4-37-1 5 PDT, 10 CKT.
A4-65 4 PDT, 8 CKT. removable plastic button
A4-73 4 PDT, 8 CKT. aluminum button
A4-111 4 PDT, 8 CKT. pushbutton w/hex seal
POTTED LEADS TYPES various models SP, DP or TP

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The industry's most complete line. Models light up in any of one to four colors, with round or rectangular buttons. All units relampable from front of panel. Make possible revolutionary ASTROMATIC panel concept which simplifies and reduces complex monitoring and control centers to small, efficient, pictorial lighted panels. Write for data on lighted switches or complete ASTROMATIC panels.

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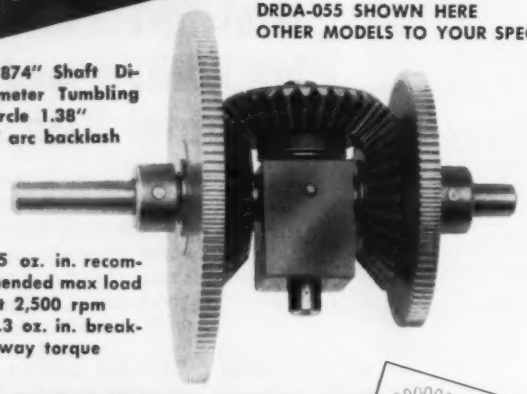

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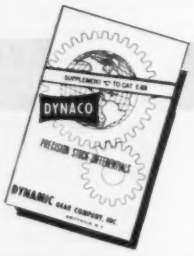

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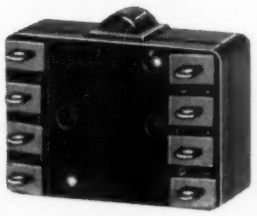
four circuit? HERE THEY ARE...

double pole



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Operating Force 23 to 33 oz.
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Termination D4 series—end solder
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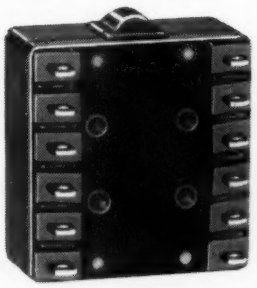
Available in simultaneous, non-simultaneous and reset models. Models available with Military and U.L. approval. Write for details.

A2-8/D8-4 roller lever
A3-10/D8-4 maintained
A4-2/D4-4
A4-24/D8-4 removable plastic button
A4-102/D8-4 1" colored plastic button
A5-14/D8-4 roller leaf
A5-18/D4-4 extension leaf
C2-9/D8-4 interlock

six circuit? THESE TOO...

triple pole



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Amb. Temp. −100° to +375° F.
Termination K1 series—end solder
K3 series—side solder

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A2-5/K3-4 roller lever
A3-10/K3-4 maintained
A4-2/K1-4
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C2-14/K3-4 interlock
C2-20-1/K3-4 solenoid hold-down

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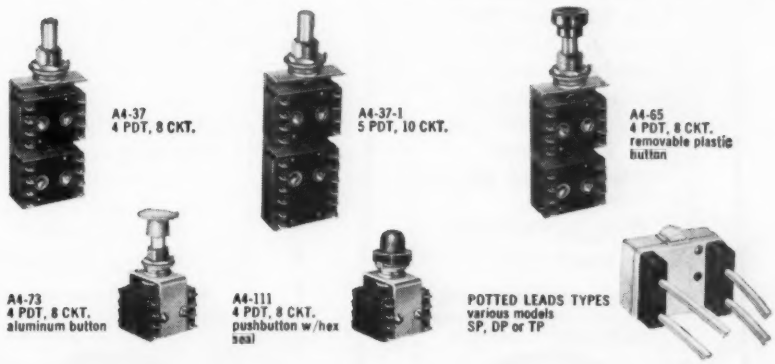

A4-37 4 PDT, 8 CKT.
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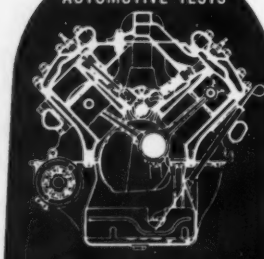

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Eight-page booklet contains solenoid valve nomenclature, description of various types of valve sealing, a discussion of mechanical specification criteria, fluid characteristics, pressure, valve capacity, leakage, valve life, speed of valve operation, and valve envelopes, electrical specification criteria including explanation of solenoid duty, electrical connections and coil construction, environmental specification criteria, testing and test specifications and safety.

Source: Valcor Engineering Corp.
Kenilworth, New Jersey
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Precision Instrument Components

416-page master catalog lists over 10,000 precision stock items, including gears, shafts, collars, couplings, speed reducers, and differentials. In addition to detailed drawings, complete specifications and prices, the new catalog contains separate technical data, breadboard kit and precision tool components section.

Source: PIC Design Corp.
East Rockaway, L.I., New York
For your copy: Circle No. 197 on Inquiry Card

Tantalum Capacitors

16-page catalog contains complete information on fifteen different types of solid, foil and sintered anode tantalum capacitors. Types range from high temperature tantalum capacitors for 200°C operation to subminiature capacitors hardly larger than a pin. A table containing over 600 listings arranged by microfarad and voltage ratings, extending from 0.25 to 1300 mfd is featured.

Source: P. R. Mallory & Co., Inc.
Indianapolis, Indiana
For your copy: Circle No. 198 on Inquiry Card

All-Purpose Panel Meters

Indicating panel meters and pyrometers in numerous sensitivities, styles and sizes, for monitoring any electrically measurable variable, are described in a 12-page bulletin. General specifications, prices, easily-read mounting dimensions, and ordering information are included. The bulletin also covers such accessories as transformers, thermocouples and shunts for use with the meters.

Source: Assembly Products, Inc.
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For your copy: Circle No. 200 on Inquiry Card

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Switches and Indicator Lights

43-page catalog describes and gives full data on a complete line of switches, (toggle, pushbutton and precision) and indicator lights.

Source: Hetherington, Inc.
Folcroft, Pa.
For your copy: Circle No. 187 on Inquiry Card

Motor-Tach Generators

16-page catalog describes a complete line of precision made motor-tach generators for scientific, military and industrial applications. General descriptive data and definitions, performance curves, dimensional drawings, and physical, electrical and mechanical characteristics are included.

Source: John Oster Mfg. Co.
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WORTH BUYING

Transistor Manual

A fourth edition of "Transistor Manual" has been published by the General Electric Co. The new book contains 227 pages of completely re-written information on transistors and their use in electronic circuits. Included in the twenty chapters is information on basic semiconductor theory, transistor construction techniques, biasing, switching characteristics and several chapters on circuits. Price $1.00.

Order your copy from:
General Electric Co.
Semiconductor Products Department
Charles Building
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Zener Diode Handbook

130 page manual covering basic theory, design characteristics and applications for zener (voltage limiting) diodes is intended to serve as a guide in the use of this versatile and relatively new component. Chapter headings include: characteristics of silicon zener diodes, design consideration, regulated power supplies, surge protection, a-c and d-c amplifiers, temperature compensation and impedance cancellation, new approaches in zener diode applications, and specifications and testing methods. Price $1.00.

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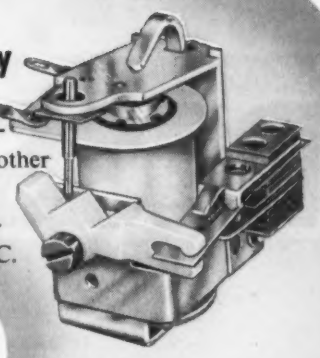
Insulated rocker arm is activated by a single coil, instead of two. Ideal for controls, appliances, positioning devices and other applications where opposite switching is desired each time circuit is pulsed. Contact combinations up to 4 "C". AC or DC.



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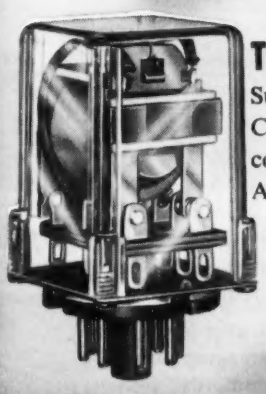
COMAR RELAYS
designed to solve your relay problems



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We specialize in supplying relays for a wide range of requirements.

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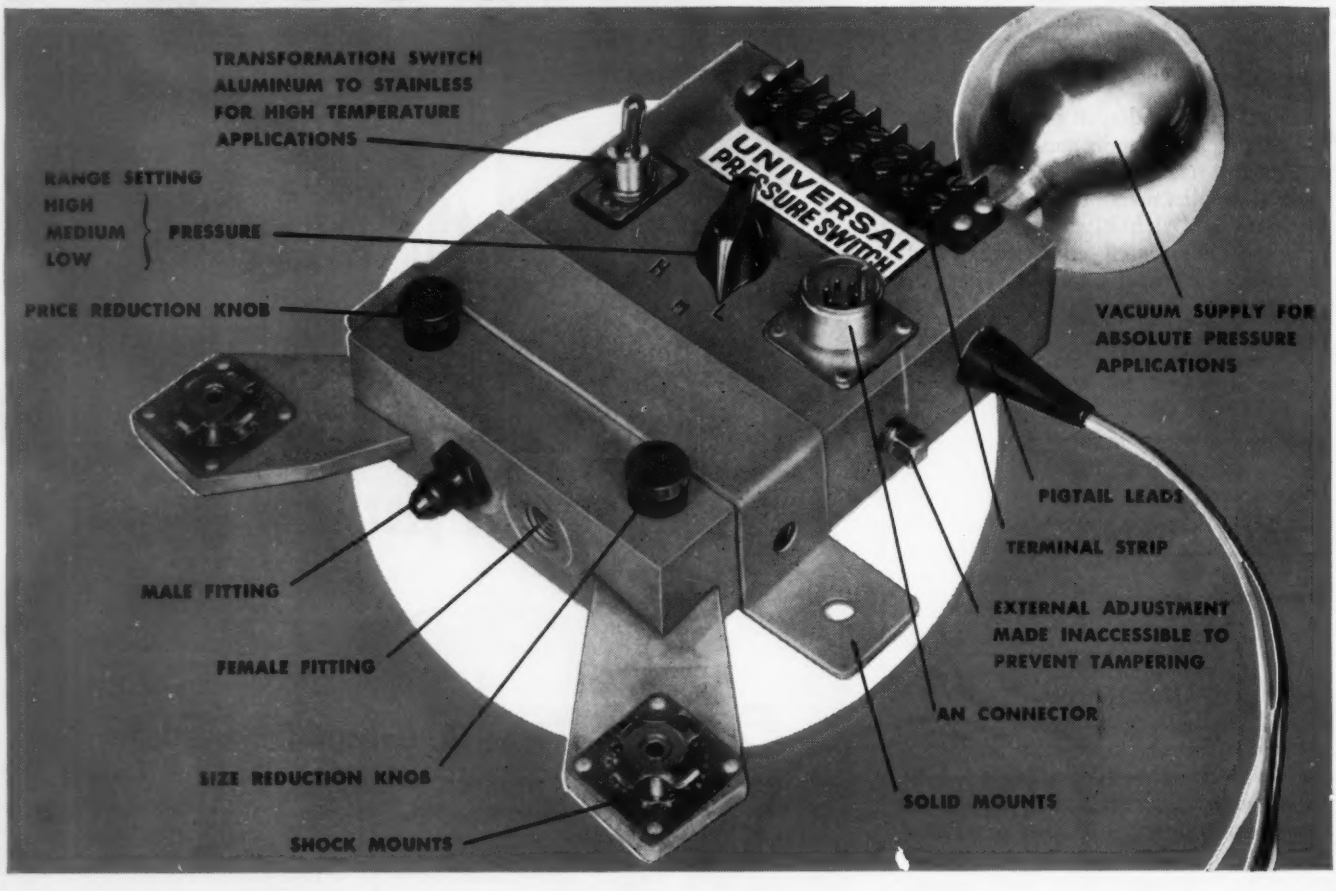
A UNIVERSAL PRESSURE SWITCH!



After years of analyzing thousands of pressure switch specifications, our engineering department concludes that one UNIVERSAL design will fulfill 33.7% of all requirements.

For the other 66.3% of pressure switch applications where the universal switch won't do, we suggest rummaging about in our catalog which tells of a full line of "standards" now in production.

AND, if you happen to have a really weird problem (currently 6.93% of all inquiries) which can't be answered by one of our standards, write to us anyway. We keep a few odd engineers who thrive on the off beat applications.

Please direct all inquiries to the Sales Department where they will be judged impartially on the basis of clarity, sincerity and volume potential. Those inquiries which clearly demonstrate a "need to know" will be answered promptly.

"FROM INCHES OF WATER
TO HUNDREDS OF ATMOSPHERES"

CONSOLIDATED CONTROLS CORPORATION

BETHEL, CONN., INGLEWOOD, CALIF.

A SUBSIDIARY OF CONSOLIDATED DIESEL ELECTRIC CORPORATION

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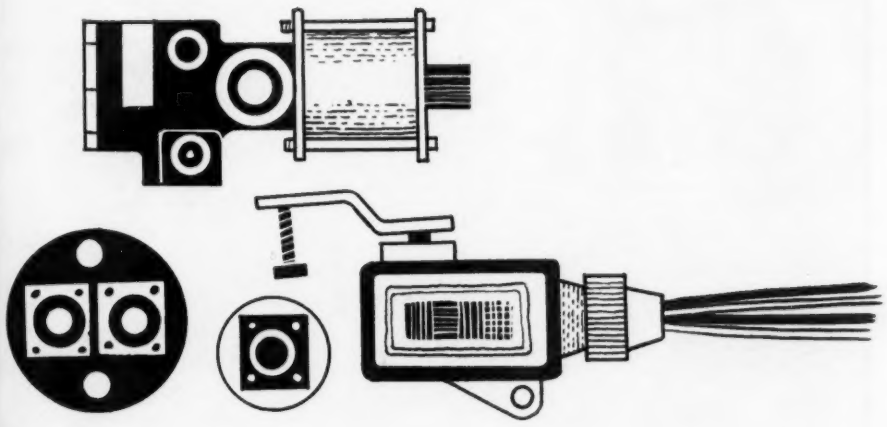


COMPONENTS DIGEST 8

Electromechanical Switches Part 2

In this part of Components Digest 8, we continue descriptions of the different types of switches, discuss their performance and application factors, and review important specifications used to describe switches for commercial and military applications.

PRECISION SWITCHES

A precision switch is one in which the output is a precise function of the position of the actuating member. Many kinds of precision switches have been developed to meet many different application requirements. A precision snap-acting switch has been defined by NEMA as a "mechanically operated electric switch having predetermined and accurately controlled characteristics." A precision snap-acting switch may consist of a basic switch used alone, a basic switch used with actuator (s), or a basic switch used with actuator (s) and an enclosure. An actuator is defined as the mechanism of the switch or enclosure which, when moved as intended, will operate the contacts." Many forms of actuator are available to suit the mechanical requirements of different applications.

Other NEMA definitions applicable to precision switches are given in Table I.

Precision switches are widely used as limit switches to control a circuit when a moving member has reached a preset point, and in somewhat similar fashion, as safety switches, where the switch can detect an unsafe travel of such a moving member.

The operation of a precision switch is based upon snap-acting contacts actuated by the motion of a plunger. Fig. 1 shows a typical construction and operating principles for this type switch. The important definitions related to the travel of the plunger and the action of the switch as a function of plunger position are listed in Table I. The short-travel of the plunger unit may be amplified for many applications

TABLE I

NEMA DEFINITIONS FOR PRECISION SNAP-ACTING SWITCHES

GENERAL

Snap Action—Snap action is a rapid motion of the contacts from one position to another position, or their return. This action is relatively independent of the rate of travel of the actuator.

Precision Snap-acting Switch—A precision snap-acting switch is a mechanically operated electric switch having predetermined and accurately controlled characteristics. A precision snap-acting switch consists of a basic switch used alone, a basic switch used with actuator(s), or a basic switch used with actuator(s) and an enclosure.

Basic Switch—A basic switch is a precision snap-acting switch of either the open type, skeleton type, or the type encased within an envelope. A basic switch is normally used within a protective enclosure or is used as a component.

Momentary Contact Switch—A momentary contact switch is a switch which returns from the operated condition to its normal circuit condition when the actuating force is removed.

Maintained Contact Switch (Reset Switch)—A maintained contact switch is a switch which remains in a given condition until actuated to another condition, which is also maintained until further actuation.

Actuator (Switch Actuator)—An actuator is the mechanism of the switch or enclosure which, when moved as intended, will operate the contacts.

Auxiliary Actuator—An auxiliary actuator is a mechanism which may be attached to a switch to modify its characteristics.

Operating Force—Operating force is that straight line force in the designated direction applied to the actuator to cause the switch contacts to snap to the operated contact position.

Pretravel—Pretravel is the distance or angle through which the actuator moves from the actuator free position to the actuator operating position.

Operating Position—Operating position is the position of the actuator at which the contacts snap to the operated contact position.

Overtravel—Overtravel is the movement of the actuator beyond the operating position. (This characteristic is usually expressed as a minimum value; however, it is recommended that this figure not be exceeded in use.)

Total Travel—Total travel is the sum of the pretravel and overtravel.

Contact Force—Contact force is the force exerted by the moving contact on a stationary contact.

Break Distance (Contact Gap)—The break distance of a switch is the effective open gap distance between the stationary and movable contacts.

Repeatability—Repeatability is the ability to consistently maintain the original operating characteristics.

MOMENTARY CONTACT SWITCHES

Normal Contact Position—Normal contact position is that position of the contacts which exists when no operating force is applied.

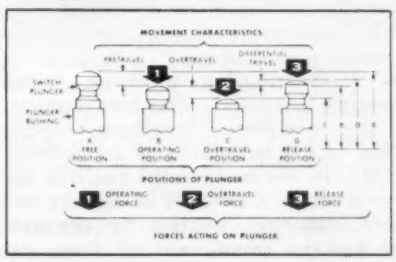
Free Position—Free position is the initial position of the actuator when there is no external force (other than gravity) applied on the actuator and the switch is in the specified position.

Release Force—Release force is the value to which the force on the actuator must be reduced to allow the contacts to snap from the operated contact position to the normal contact position.

Force Differential—The force differential is the difference between operating force and the release force.

Releasing Position—Releasing position is that position of the actuator at which the contacts snap from the operated contact position to the normal contact position.

Movement Differential—Movement differential is the distance or angle from the operating position to the releasing position.



COMPONENTS DIGEST

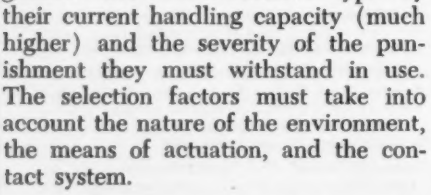
by an appropriate actuation using the lever principle. The actuator configuration is adaptable to the configuration of the apparatus which the switch is to control. Fig. 2 shows some actuator designs by Haydon Switch, Inc. Fig. 3 shows switch actuator assemblies of hermetically-sealed precision switches by Electro Snap. To adapt a precision switch to an application, the available motion must be converted to the required operating motion for the basic switch. This is the function of the actuator. Available force configuration, and mechanical travel govern the choice of actuation.

The proper application of a precision switch involves selection of the switch, choice of actuator, and correct installation. Table II lists the items to be considered, with descriptions.

The chart of Table III shows the effects of temperature on a Unimax precision switch. The specific curves high-light the aspects of performance listed in Table II, indicating the general nature of the variations to be expected under extreme temperature conditions. Figs. 4 through 11 show some of the many types of precision switch-actuator combinations.

HEAVY-DUTY LIMIT SWITCHES

Heavy duty limit switches are distinguished from the sensitive type by their current handling capacity (much higher) and the severity of the punishment they must withstand in use. The selection factors must take into account the nature of the environment, the means of actuation, and the contact system.



COURTESY MICRO SWITCH

Fig. 1—Snap-acting precision switch operating principles. The long member of the one-piece beryllium copper spring (C) is supported as a cantilever at (M). In the unoperated position the silver contact (A) is held against the upper stationary contact by the vertical upward component of force exerted by the side members of the spring. The two side blades (compression members) are supported in grooves in the anchor (D). Depression of the plunger (E) snaps the moveable contact from the upper stationary contact to the lower one.

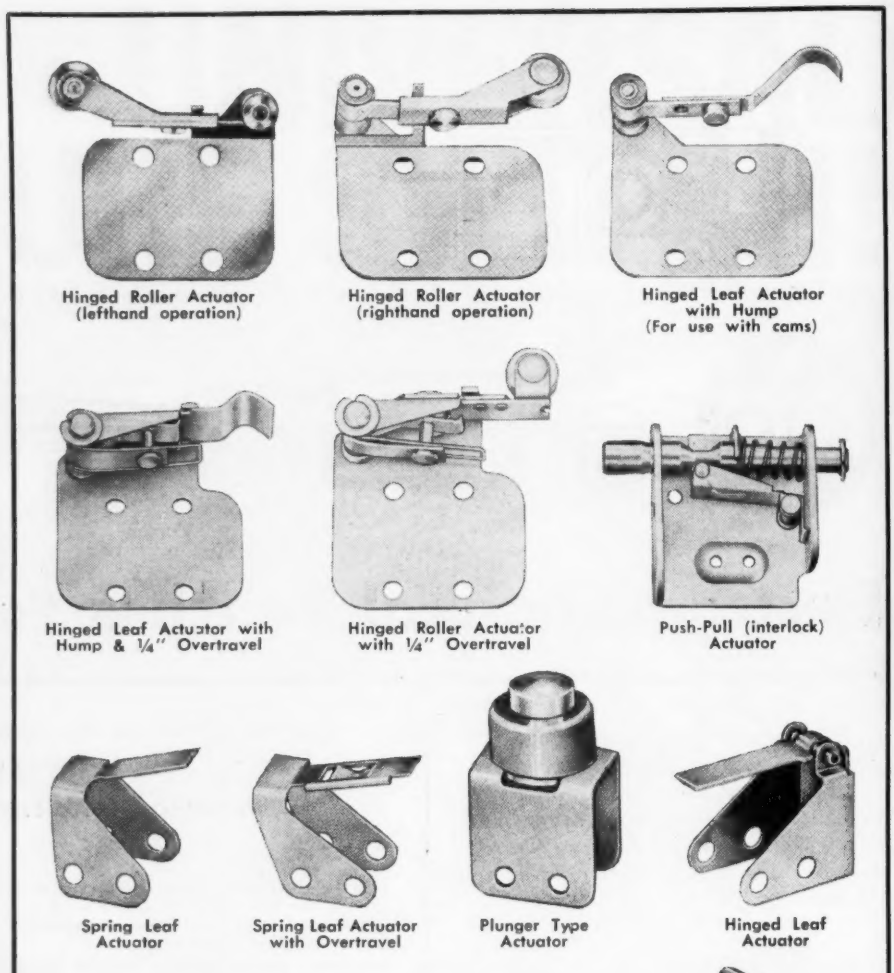

Hinged Roller Actuator (lefthand operation)
Hinged Roller Actuator (righthand operation)
Hinged Leaf Actuator with Hump (For use with cams)
Hinged Leaf Actuator with Hump & 1/4" Overtravel
Hinged Roller Actuator with 1/4" Overtravel
Push-Pull (interlock) Actuator
Spring Leaf Actuator
Spring Leaf Actuator with Overtravel
Plunger Type Actuator
Hinged Leaf Actuator
Hinged Roller Actuator
Hinged Leaf Actuator with added overtravel
Hinged Roller Actuator
Plunger Type Actuator
Push Button Actuator
Hinged Roller Actuator (lefthand operation)
Roller Plunger Actuator

Fig. 2—Some of the many types of actuators which may be used with precision switches in specialized applications.

Because heavy-duty limit switches are generally located right at the control point where parts are being machined or other severe action is taking place, they must be protected from the normal industrial hazards of shock and vibration, corrosive vapors, coolants and cutting oils, flying chips, dust and other contaminants. To meet these severe conditions gasket sealing is commonly used. However, since this is not hermetic sealing, humidity under changing temperatures, as well as particularly heavy splashing of liquids can contaminate the internal switch elements. Suitable switch location and orientation, and some kind of seal at the wiring conduit (through which moisture frequency enters) will minimize problems of this type.

It is particularly difficult to protect standard switches from corrosive fumes although suitable sealing techniques will extend switch life. For true protection, hermetically sealed units similar to military types are required. Since

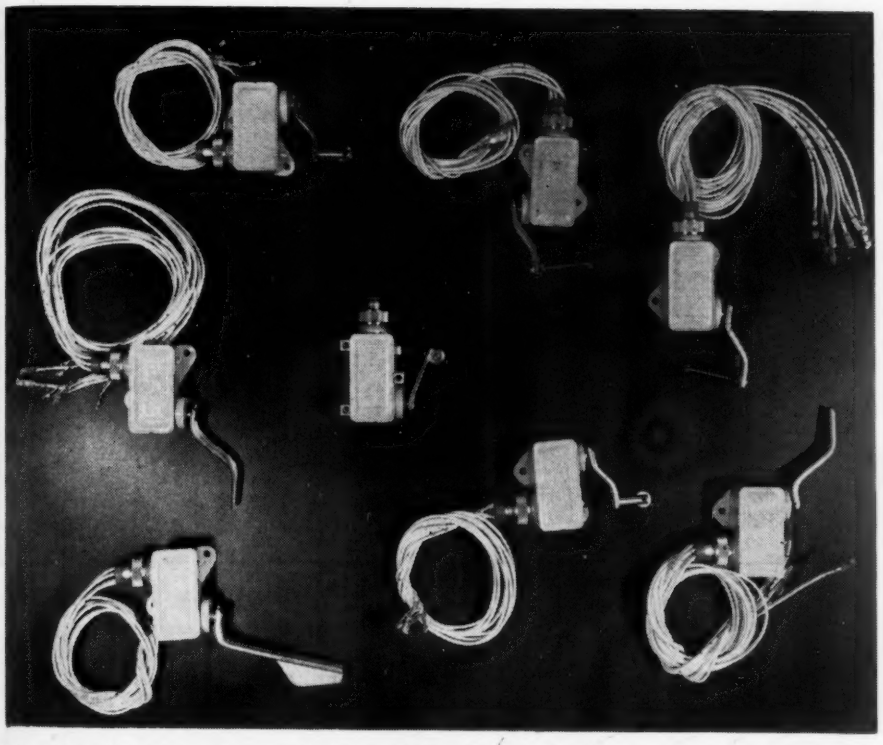


Fig. 3—Electrosnap hermetically sealed switches showing variety of actuator assemblies.

such units are generally of low capacity, they may be used in conjunction with a remotely located relay which has been removed from the vicinity of the corrosive atmosphere.

Shock and vibration effects which are most severe on punch press applications may be minimized by suitable orientation of the switch so that the principle forces do not tend to cause a false switch operation. The switch design itself can be made less shock sensitive by minimizing masses and using high contact pressure.

ACTUATING THE HEAVY-DUTY SWITCH

The principal cause of failure of heavy-duty limit switches is as a consequence of the impact forces involved in the actuation of high speed systems. The actuation system should be designed to provide smooth accelerations, minimize impacts, avoid sudden release and snapping back of the actuator arm, and in general minimize the strains on the switch assembly. Where long life and good repeatability are required, overtravel (the movement of the actuator beyond the point of switch action) should be minimized because of the strain imposed not only on the switch assembly but also on the internal spring. Wear on the actuation surfaces will result in a gradual shift in the switch operating point. The design of actuation elements must be based upon ordinary principles of cam actuation, as well as the manufacturers' specifications for the switch. Protection is necessary for excessive travel which may destroy the switch. Table IV gives suggestions by NEMA (Pub. No. 1C3-1959) for the proper application of industrial limit switches.

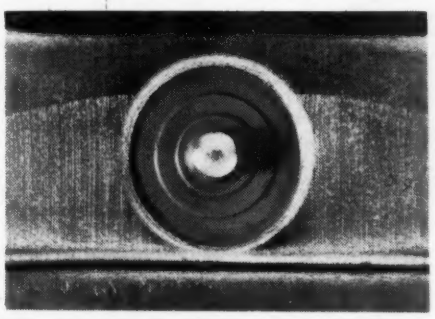


Fig. 4—Hermetic sealed switch by Haydon impervious to the deteriorating effects of JP-4 fuel. Evaluation tests in the laboratory show that the new seal construction resists JP-4 fuels for over one million cycles with an immersion time of eight weeks. The cycling tests were conducted at a low temperature of minus 65F and a high temperature of 250F without ill effects to the seal. Laboratory tests also showed that the new seal withstands 155 PSI differential pressure for six hours with no evidence of leaks.

PRESSURE SWITCHES

Pressure switches as the name implies are switches whose response is a function of the gas or liquid pressure which they are designed to regulate and control. Applications include response to altitude, air speed, fuel pressure, liquid level, air flow, hydraulic pressure, depth pressures (undersea). Switches may respond to absolute, gauge or differential pressures. By means of adapting elements, these switches may be applied to a great variety of applications such as measuring air flow, for example. Table V presents pressure switch terminology as applied by Consolidated Controls Corp. Fig. 12 illustrates, diagramatically, the operating points in a snap-acting pressure switch, as illustrated by Barksdale Valves. These may be compared with similar designations for snap-acting switches as previously presented. Figs. 13 through 16 describe some commercially available pressure switches.

Environmental Factors—The environmental factors applicable to switches in general may be directly applied to pressure switches. The switch must be designed to withstand the extreme pressures occurring under transient or fault conditions without damage. False actuation due to shock and vibration,

TABLE II

PRECISION SWITCHES PERFORMANCE AND APPLICATION FACTORS

REPEAT ACCURACY

For many control applications repeatability is important. Accuracies are available to 0.0001 inch. However, drift occurs with temperature variation and use, and manufacturers often specify repeatability in 100,000 successive operations. For precise applications, only light electrical loading is permissable to avoid contact sticking.

DIFFERENTIAL MOTION

Where the switch is used in conjunction with pressure and temperature sensing elements for control purposes, a close differential motion is required between operate and release position. Differential motions of the order of 0.0002 inches are available.

OPERATING FORCE

This force depends on spring stiffness and contact separation. The available force in most machine tool application is ample for positioning controls. In measurement and regulator applications, a uniform force with a close differential between operate and release is important.

LOAD FACTORS

Heavy loads cause contact stickiness and reduced repeatability. Contact materials must be related to load requirements, both as regards capacity at high power levels, and low contact resistance at milliwatt power levels. Operating forces are higher in heavy load switches.

LIFE

Mechanical life is determined by the fatigue characteristics of the spring. Wide contact spacing in high voltage units means more spring motion, greater fatigue stresses, and shorter life. Electrical life depends very much on proper operation within the contact ratings, as discussed in Part I of this Components Digest. Inductive loads, lamp and motor loads, contact source and welding of contacts are factors governing contact life.

COMPONENTS DIGEST

or pressure fluctuations must be avoided. Units are available with integral shock mounts, see Fig. 17 (this figure also shows a typical vibration test result for a pressure switch). Ambient temperatures of 650F and higher can be withstood by some switches.

THERMAL SWITCHES

The varieties of switches previously described cover the great majority of general purpose applications. In addition to these, there are many specialized switch types which are more or less widely used, the commonest being the thermal switch.

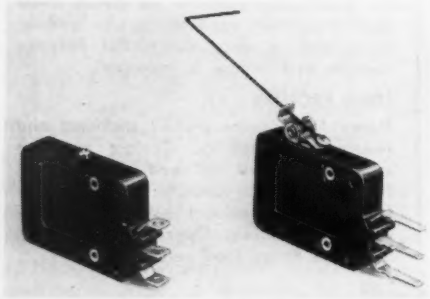


Fig. 5—These switches by Haydon Switch, Inc. are qualified to the basic snap-action switch specification MIL-S-6743 and the vibration requirements of MIL-E-5272A, Procedure II. Other types feature the actuating button in off-center position, and extremely low operating forces. Furnished with pin, integral wire or flat leaf actuators, these models cover an operating force range of 2.5 to 60 grams.

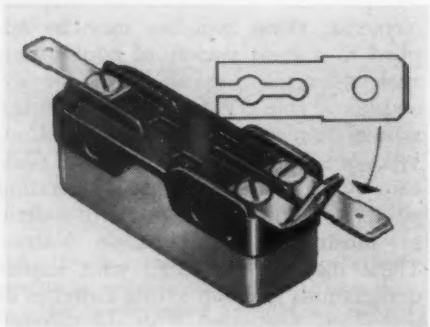


Fig. 7—New quick-connect terminals for high-sensitivity snap-acting switches. New male snap-on terminals provide firm, vibration-resistant installation to high-sensitivity snap-acting miniature switches. The new terminals fit between the molded barriers on the Unimax switch base, and the securing screw spreads the slotted end to give solid, no-turn installation that resists shock and vibration.

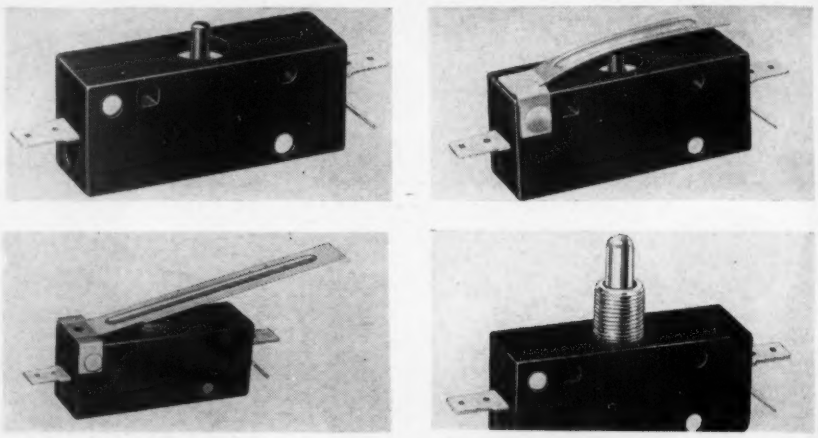


Fig. 6—Snapac switches by Controls Company of America showing variety of actuating means.

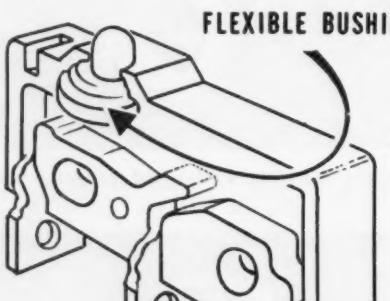


Fig. 8—Sealed subminiature switch provides splash-proof, dust-proof, explosion-proof operation. The Unimax subminiature snap-acting switch was developed for use in applications, where small size, reliability, safety in explosive atmosphere, with sealing against moisture, dust, and splashing liquids are essential. The switch has a flexible bushing compressed around the pin actuator inside the phenolic case.

Fig. 9—One of Electrosnap's hermetically sealed switches for aircraft use. Widely used to indicate position of landing gear, bomb bays, etc.

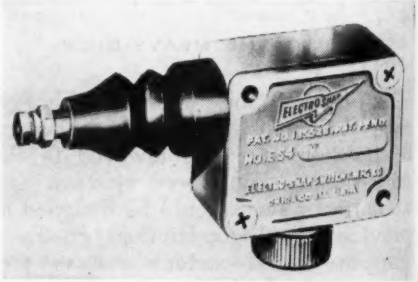


Fig. 10—One-way switch with rubber boot on actuator to protect it from splashing oil and water, dirt and metal chips.

COURTESY ELECTROSNAP CORP.

Fig. 11—Electrosnap hermetically-sealed switch on aircraft landing gear.

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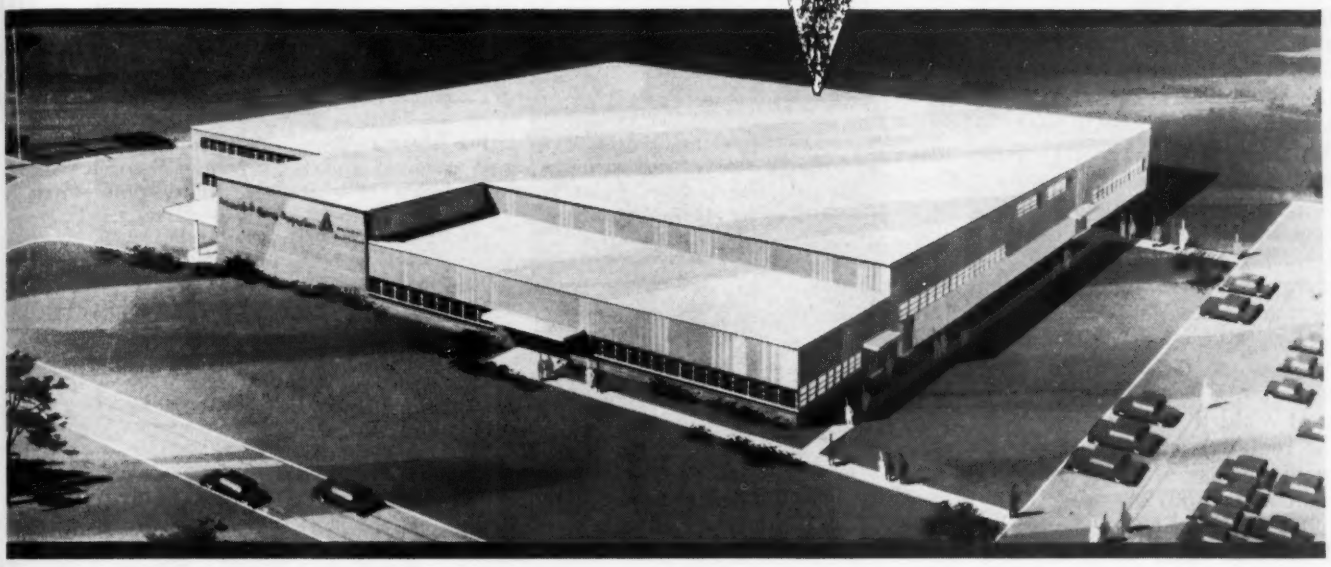

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CIRCLE 54 ON INQUIRY CARD

COMPONENTS DIGEST

Thermal switches are used either for the indication or control of temperature, or in a protective function. The majority of these are simple thermostatic-like devices whose performance depends upon the action of a bi-metallic element. The principal design factors relate to accuracy and repeatability, temperature range, thermal lag, configuration, and ruggedness. Often the nature and capacity of the contacts constitute additional factors. Specific switch designs may feature compactness, low thermal time lags, extremely high temperatures, high resistance to vibration and shock (as for jet aircraft application) and hermetically sealed types which provide thermal indication with minimum drift under extreme shock, vibration, and other severe environmental conditions. Such units generally employ stainless steel welded construction to achieve the required reliability. Environmental requirements are generally derived from MIL-E-5272A.

Thermal controls are particularly difficult to apply in closed loop temperature regulating systems because of the time lags in response which generally characterize such systems. Fenwal describes the approach to successful operation of a temperature regulation system; some of their recommendations are summarized below.

Thermal Switch Application—There are two separate aspects to any temperature control problem: proper installation of the thermostat within a well designed control system, and proper design of the heat system and the relation of the thermostat to it.

In any typical thermal control application, the total variation of temperature about the desired value is

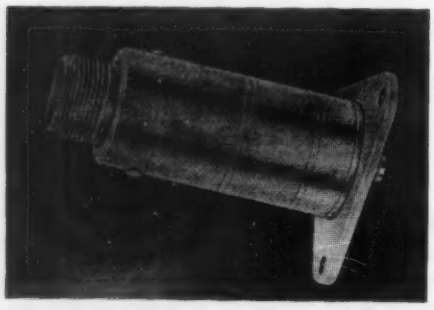

Fig. 16—High temperature pressure switch by Consolidated Controls Corp. This switch is rated for continuous duty at temperatures up to 650F. The performance is attained by use of all-welded stainless steel construction, an advanced type of snap-action switch element, and a precision stacked-capsule sensing element. Operating media include standard aircraft fluids, air hydraulic fluids, MIL-O-5606, MIL-L-7808 and others. Primarily utility is in airframe, missile and rocket appli cations, particularly in hot spots near engines or where air friction raises temperatures. Vibration performance meets the requirements of MIL-E-5009A.

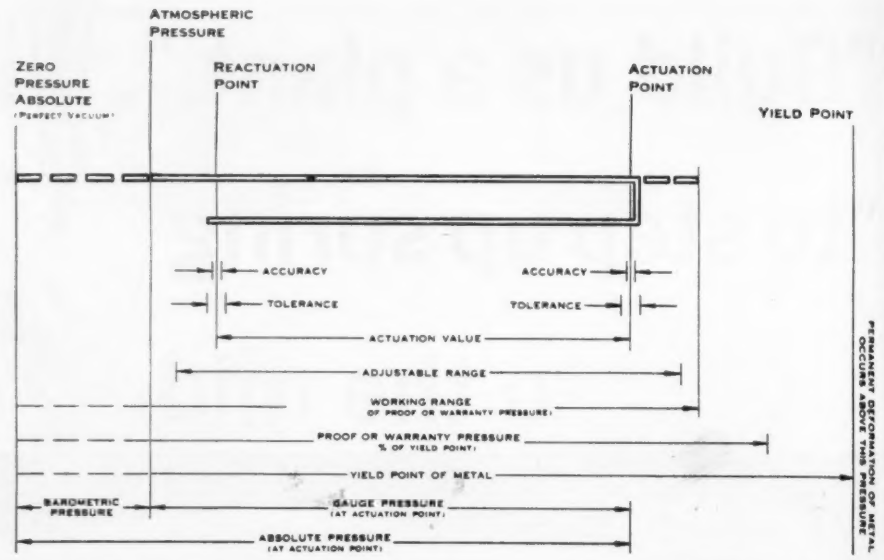

Fig. 12—Operating points, snap acting pressure switch. Adjustable range is pressure range within which the actuation point of a pressure actuated switch may be adjusted. Reactuation point is the pressure at which the snap-action switch is restored to its original circuit.

Fig. 14—Differential pressure switch. This is a multiapplication, pressure operated electrical switch, designed for military and commercial use. The pressure switch is of aircraft quality and fabricated for pneumatic or hydraulic systems operating with pressures up to 5000 PSI. The pressure switch is sensitive to, and actuates from differential pressures within a system or unit, and moves to positively trip an electrical switch. The switch employs a spring loaded poppet valve which, when moved off its seat, exposes a secondary surface for the pressure to act against. The poppet is immediately forced to the full open position. When the poppet moves from the secondary position to the full open position, a cam lever is actuated and trips an electrical switch to make or break a circuit. The pressure switch is available with a normally open or normally closed switch.

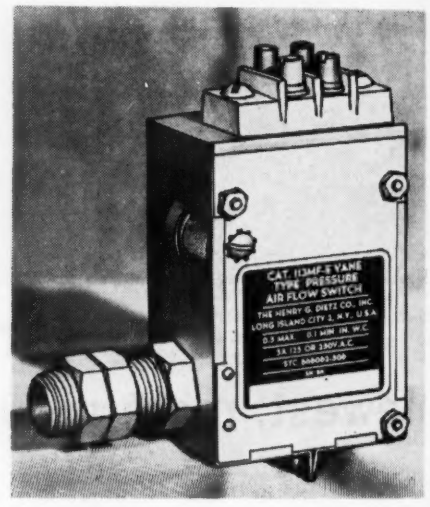

Fig. 13—Air flow interlock for use in forced air cooling of electronic equipment. This is a vane type pressure air flow switch used as an air flow interlock in forced air cooling of electronic equipment built to military specifications. It is designed to operate a control relay when a predetermined minimum flow of air occurs due to: partial loss of power of a three phase system; loose boots, clamps, or flanges in duct; or any other air-flow impeding factor. A decrease in air-flow results in excessive temperatures in vacuum tubes. Resistors become unstable, capacitors decompose and suffer dielectric failure. The insulation resistance of paper capacitors may be halved for each 10C increase in work temperature. Thus poor reliability is associated with excessive temperature that can resu!t from air flow failure. This switch operates on the static pressure plus the velocity pressure and, therefore, a substantial amount of force is available for operation of the interlock. Pressure interlocks are relatively immune to shock and vibration.

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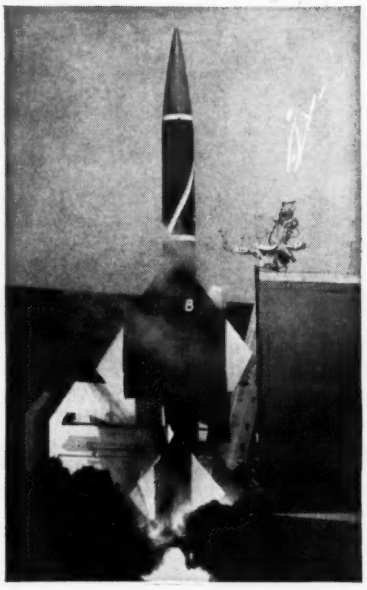

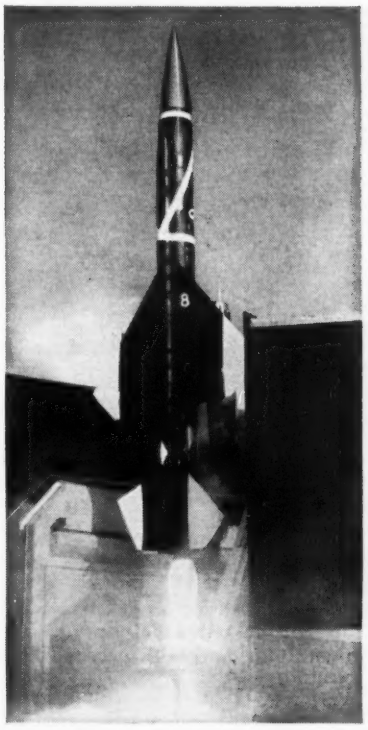

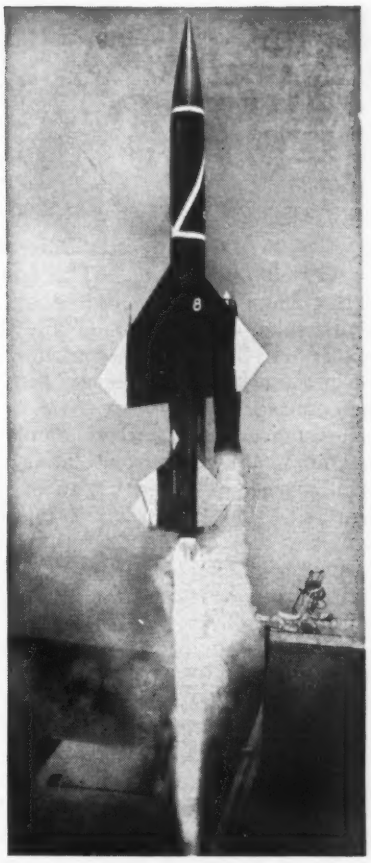

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COMPONENTS DIGEST

larger than the thermostat differential as a result of "hunting". The amount of this temperature variation about the mean value is determined by three factors: (1) heater characteristics, (2) the process being controlled, and (3) the controlling thermostat.

Resistance type heaters employ a minimum amount of insulating material, reducing heater lag to a minimum. Intimate association of this type of heater to the process produces a minimum lag effect. Radiant type heaters usually have a small lag and transfer a substantial portion of the heat to the process by means of radiant energy.

Process Characteristics–Transfer of heat from the source to the process should be as effective as possible. If the process consists of a metal unit, the heater should be cast into the block itself. If this is not possible, the heater should be in direct and firm contact with as large an area as possible. In processing involving metallic objects, the metal used should have high heat conductivity and a low value of specific heat to prevent excessive gradients within the metal structure.

In the case of liquids, placing the thermostat only a few inches above the heaters will give better control. With gases the best position of the control unit is directly above the heating element in the lower part of the oven. The result is rapid cycling and greater control. The use of an agitator is recommended for liquids and gases to reduce the heat gradient throughout the entire process.

Uniformity of temperature within the process to be controlled can be obtained by distributing the heat or heaters over as large a portion of the process as possible.

To provide minimum temperature variations from heat transfer lags at the point of control, the sensitive portion of the control and the heat source should be placed as close together as possible but not in direct contact. The thermostat naturally controls the temperature of only the region in which it is located.

MOTOR PROTECTION

The Spencer Thermostat Division of Metals and Controls Corp. as well as other manufacturers, provide thermal switches for use with rotating electrical machinery. Most often these serve as

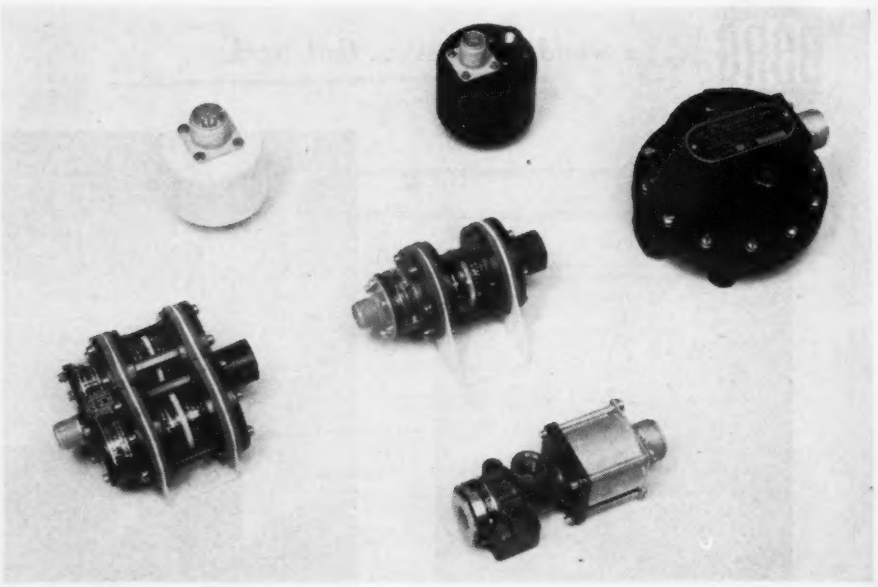


Fig. 15—Pressure switches with integral vibration isolation, made by Consolidated Controls Corp. Integral vibration isolation between the mounting bracket and switch body makes possible good performance under vibration and shock conditions. Switch performance remains well within tolerances. An SPDT snap-action switch element is employed. These units provide an external adjustment for changing the operating point. External readjustment of the set point can be made with the unit installed for operation. These units can be used with the standard aircraft fluids and with corrosive media such as oxidizers, rocket fuels, and MIL-O-7808 oil.

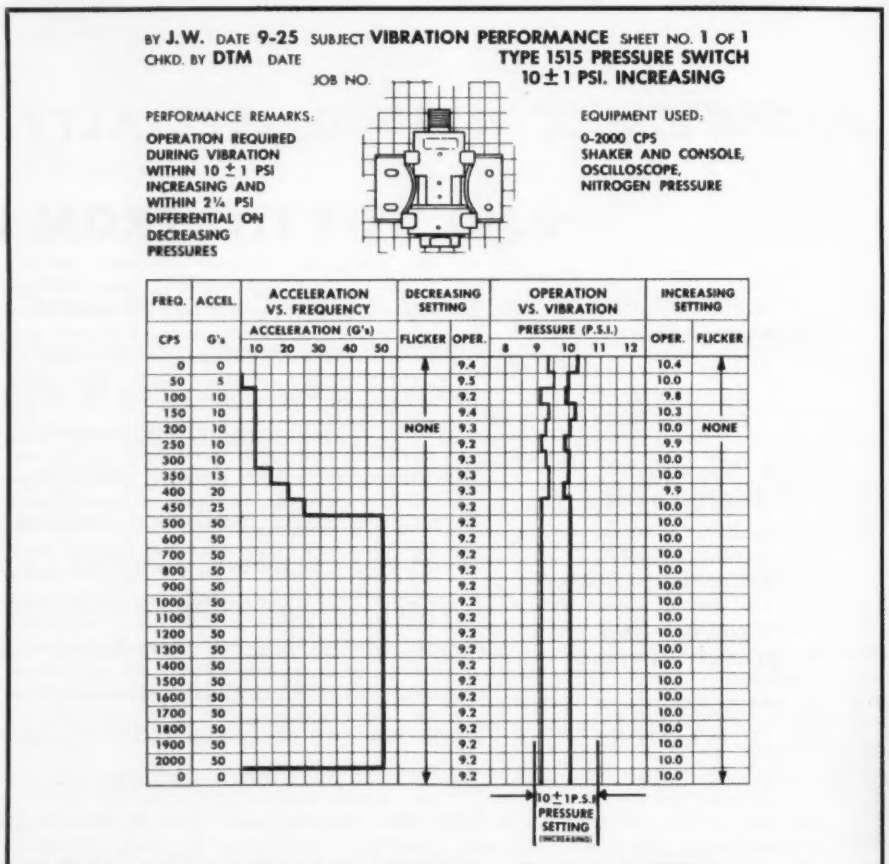
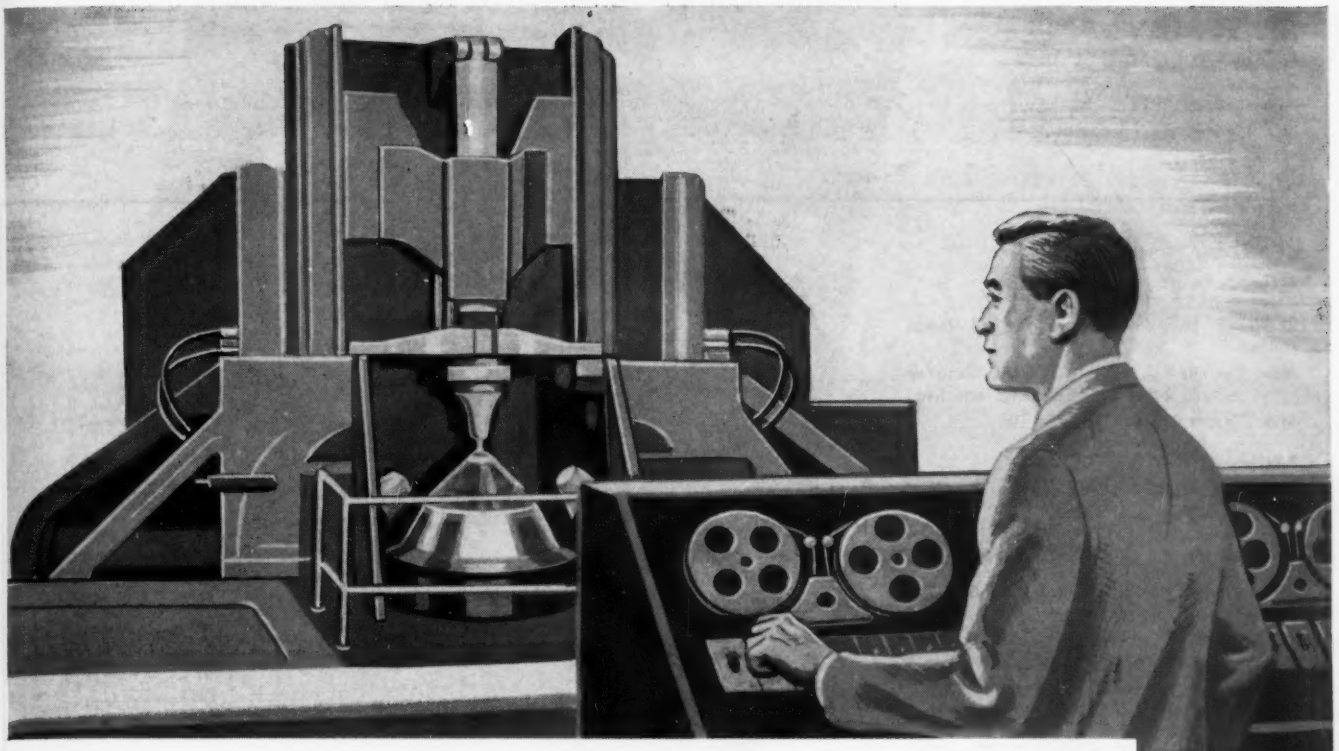


Fig. 17—Operating performance of the Haydon 1500 series pressure switch during vibration at up to 2,000 cps at 50g. Actuation remains within tolerance limits at all times, with no flicker at any point during test. A vibration isolator is optional, and not an integral part of the pressure switch assembly. Isolation is provided by a molded insert located between the mounting bracket and the switch housing. The assembly will withstand severe vibration and shock loads, offering isolation from 200 cps and up in the standard production version.



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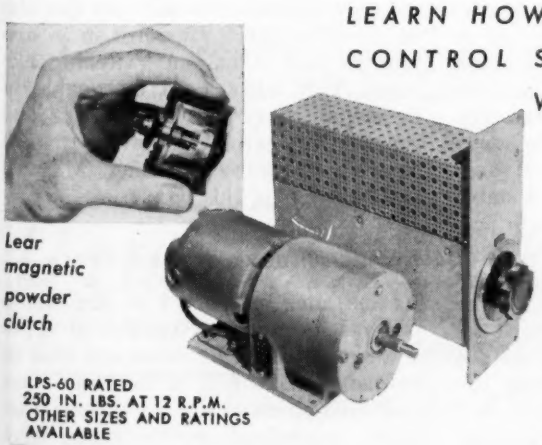
SPEED CONTROL
FLUID TRANSMISSION



Lear magnetic powder clutch

LPS-60 RATED
250 IN. LBS. AT 12 R.P.M.
OTHER SIZES AND RATINGS AVAILABLE

LEARN HOW THE LEARTRON 60 PRECISION REMOTE CONTROL SAVES TIME, MONEY AND MANPOWER. WRITE . . .

LEAR G-7

ELECTRO-MECHANICAL DIVISION

110 IONIA AVENUE, N.W. • GRAND RAPIDS, MICHIGAN

CIRCLE 56 ON INQUIRY CARD

COMPONENTS DIGEST

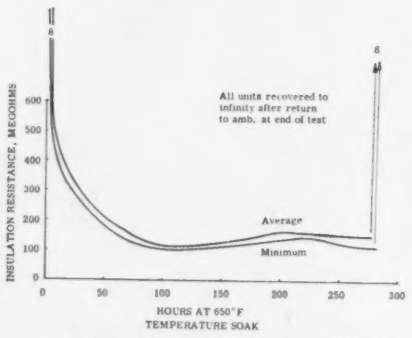
TABLE III

Test Results on Precision Switch Under Extreme Environmental Conditions

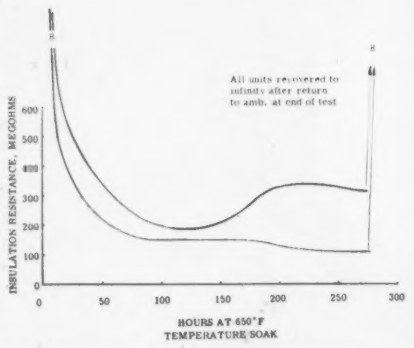
Switch Type FC-2, Unimax Switch Div., W. L. Maxson Corp.

Specifications:

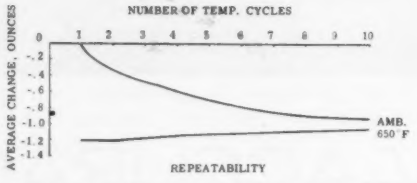
1. Temp. Range —65F to +650F
2. Rating (Applicable through full temp. range)
   Max. Current 4.0 Amp. 18-30V D.C. Resistive
   2.5 Amp. 18-V. D.C. Inductive
   Min. Current 0.1 Amp. 18-V.
3. Life
   Mechanical 100,000 operations average
   Electrical 25,000 operations
4. Temperature soak—250 hrs. at 650F
5. Temperature Shock — from —65F to +650F within one minute
6. Vibration—Switch to withstand:
   1)Procedure I, Par 4.7.1, MIL-E-5272A
   2)10g from 500 to 2000 cps.
7. Shock—Method 202A MIL-STD-202A (50g)
8. Salt Spray—Method 101A Condition A MIL-STD-202A (96 hours)
9. Fungus—Procedure I, Par. 4.8.1 MIL-E-5272A


INSULATION RESISTANCE, MEGOHMS
All units recovered to infinity after return to amb. at end of test
Average
Minimum
HOURS AT 650°F TEMPERATURE SOAK

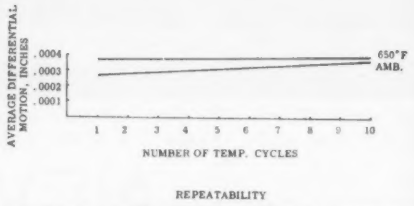
INSULATION RESISTANCE ACROSS CONTACT GAP VERSUS TIME AT 650F


INSULATION RESISTANCE, MEGOHMS
All units recovered to infinity after return to amb. at end of test
HOURS AT 650°F TEMPERATURE SOAK

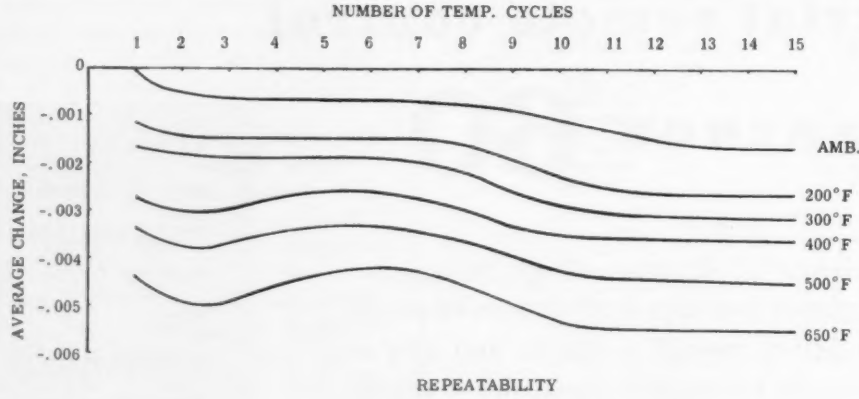
INULATION RESISTANCE FROM TERMINALS TO GROUND VERSUS TIME AT 650F



AVERAGE CHANGE IN OPERATE FORCE VERSUS NUMBER OF TEMPERATURE CYCLES



AVERAGE DIFFERENTIAL MOTION VERSUS NUMBER OF TEMPERATURE CYCLES



AVERAGE CHANGE IN OPERATE POSITION VERSUS NUMBER OF TEMPERATURE CYCLES

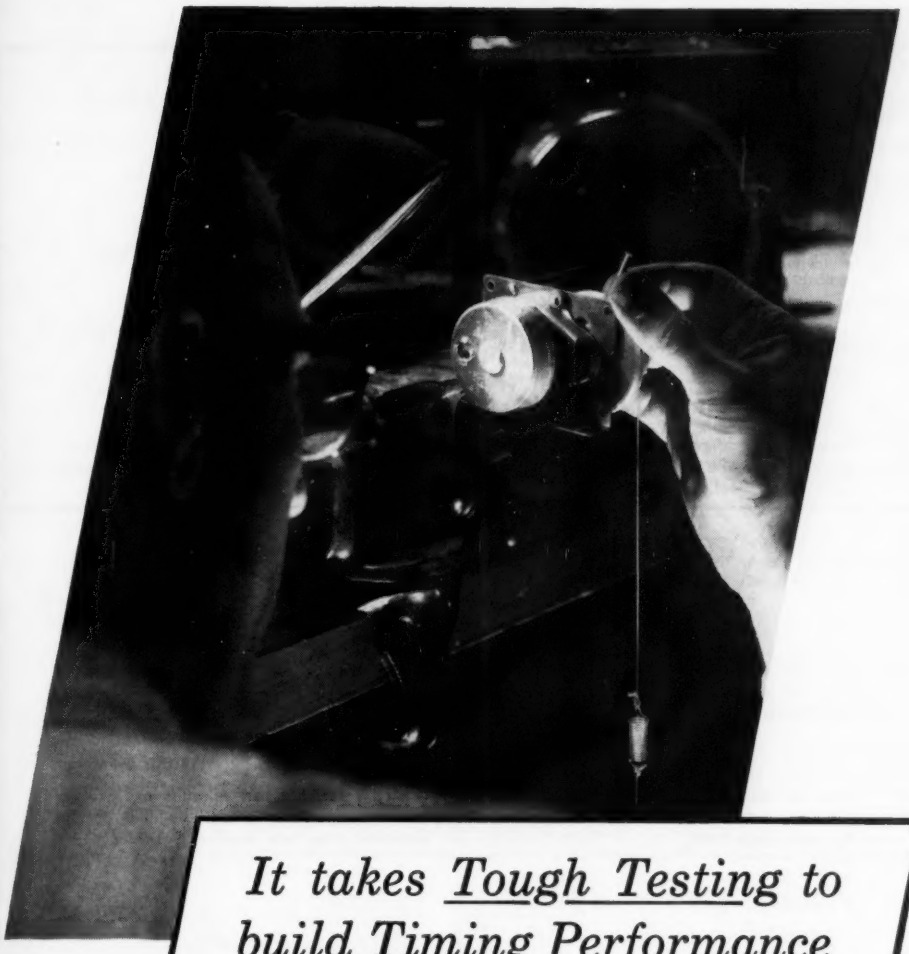
overheating protection. Operation may be based upon actuation by heaters responding to line current (which detect an overload or stall motor condition) or by excessive total ambient temperatures (including equipment temperature rise). Such thermostatic devices are particularly useful in military equipment where maximum motor output is required, and reliability is paramount. Where ambient temperatures in the vicinity of the motor are low, the thermostat will allow the motor to deliver more output before its safe temperature rise is exceeded, and vice-versa. Intermittent duty motors with high momentary peak outputs are properly protected with thermal switches. Self-cooled fans, upon whose proper functioning may depend the life of heavy electronic gear, often employ thermostats which quickly shut off power if the fan ceases to deliver an adequate amount of cooling air.

Thermostats are also employed in temperature regulation of precision electromechanical components such as integrating tachometer generators. Here the requirements include clean snap-action to avoid generation of radio interference, close differentials, a stable regulation point, and adequate capacity for the heater current. As in all such applications the thermostat must be in good thermal contact with the elements whose temperature must be controlled. Contact considerations are the same as for other switching devices.

Other thermal switching devices are available. Thermometers may incorporate contacts at various levels which are actuated by the expansion of the mercury column. The mercury can also be used to exert pressure on a diaphragm and actuate a switching element. This latter type is capable of developing large switching forces and consequently can be made very rugged. The Vapoflash by Manning, Maxwell and Moore is of this type.

MISCELLANEOUS SWITCH TYPES

As indicated in Part I of this Components Digest, the variety of types is almost endless. Switches are used in so many places and in so many ways and environments are so diverse that many specialized switch types have



It takes Tough Testing to build Timing Performance

When you buy a Haydon Timing Motor or Timing Device, you buy high quality and superior performance, because every production model and every new design has *proved* itself by passing the toughest, most exhaustive series of tests that our engineers can devise.

Quality control at Haydon starts with a careful inspection of all in-coming materials. It continues throughout production — with all parts and assemblies gaged, inspected or physically tested after every operation that can affect the performance of the finished motor or device. Final step is an inspection of completed motors and timing devices. All units are performance tested for many hours under varying conditions and are checked for quiet operation. Percentage samples of each lot are checked for torque rating, timing accuracy, and accuracy and alignment of gears and shafts. In addition, all new designs and periodic samplings from production are subjected to special "life endurance" tests in which hundreds of units are run continuously under various load conditions. In some instances, units have now been running ceaselessly for more than 10 years . . . proving their ability to perform *millions of cycles without failure!*

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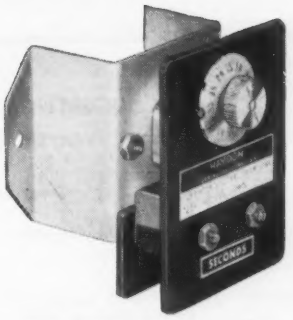
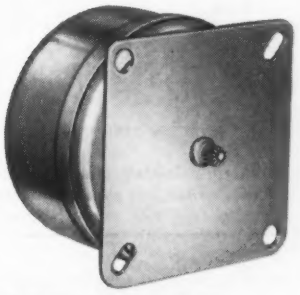


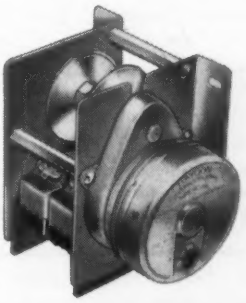
TIME DELAY TIMER

Provides time delay in ranges up to 9.5 minutes. Ideal for such applications as the protection of power tubes and/or operating preset operating cycles. Available in 120 or 240 volt, 50 or 60 cycle current.



400 CYCLE MOTOR

These split phase motors provide the military an accurate approach to timing control for military applications. Rotor speed is 3,000 RPM at 400 cycles, 115 volt normal. Two models are available — Heavy Duty with 18 gram millimeters torque at the rotor, and the Miniature with 5 gram millimeters at the rotor. These motors may be applied to Haydon gear trains if desired.



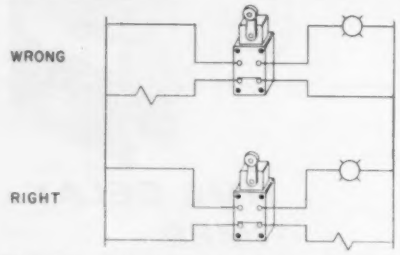
CYCLE TIMER

These units repeat a set cycle or sequence of operations as long as the motor is energized. Available in a wide choice of speeds, a broad range of timing intervals, and with a wide range of enclosed single pole, double throw switches for 120 and 240 volt operation, for 50 and 60 cycles.

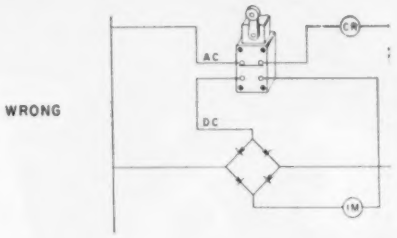
CIRCLE 57 ON INQUIRY CARD

TABLE IV

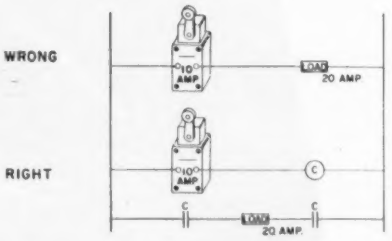
SUGGESTIONS FOR THE PROPER APPLICATION OF INDUSTRIAL LIMIT SWITCHES



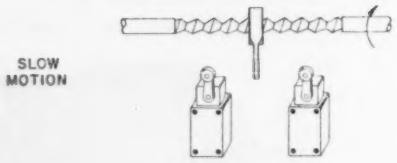
Opposite polarities should not be connected to the contacts of one limit switch unless the limit switch is specifically designed for such service.



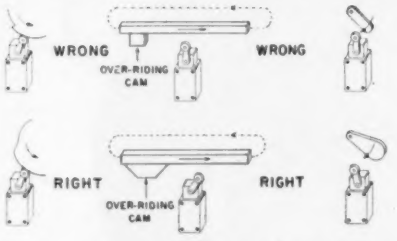
Power from different sources should not be connected to the contacts of one limit switch unless specifically designed for such service.



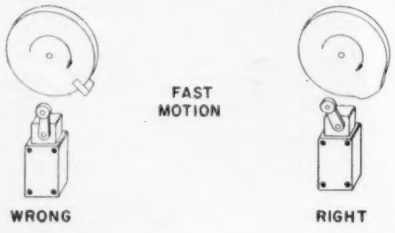
Limit switches should be used within their contact ratings.



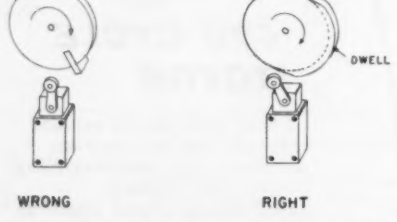
Where relatively slow motions operate the limit switch, it should generally be snap-acting.



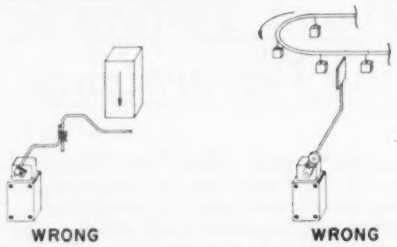
Cam or dog arrangements should be such that the actuator is not suddenly released to snap back freely.



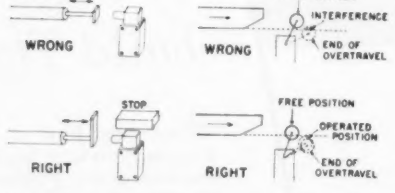
Where relatively fast motions are involved, cam arrangements should be such that the actuator does not receive a severe impact.



Where relatively fast motions are involved, cams should be designed such that the limit switch will be held operated long enough to operate relays valves, etc.

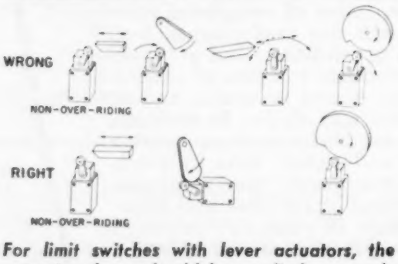


Limit switches are designed for proper performance with the actuators with which they are supplied. Supplementary actuators should not be used unless the limit switches are specifically designed for them.

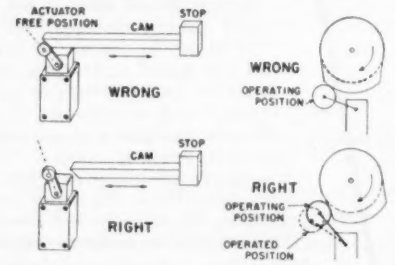


Operating mechanisms for limit switches should be so designed that, under any operating or emergency conditions, the limit switch is not operated beyond its overtravel limit position. A limit switch should not be used as a mechanical stop.

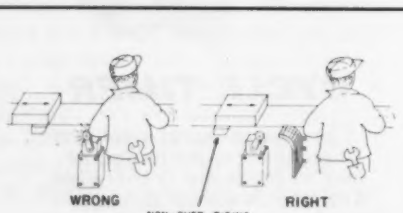
For limit switches with pushrod actuators, the actuating force should be applied as nearly as possible in line with the pushrod axis.



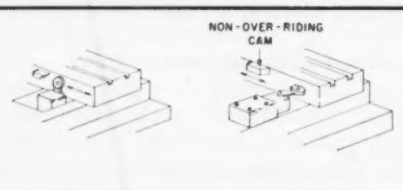
For limit switches with lever actuators, the actuating force should be applied as nearly perpendicular to the lever as practical and perpendicular to the shaft axis about which the lever rotates.



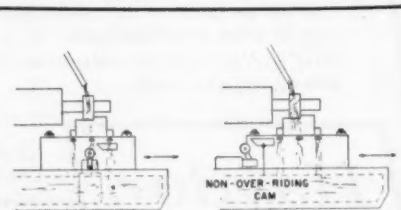
A limit switch actuator must be allowed to move far enough for positive operation of the contacts.



Limit switches should be mounted in locations which will prevent false operation by normal movements of operator or machine components.

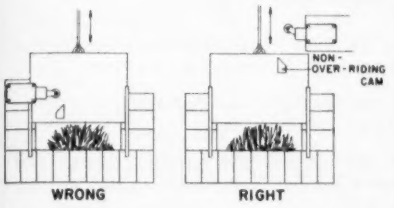


Limit switches should be mounted rigidly and in readily accessible locations, with suitable clearances to permit easy service and replacement when necessary. Cover plates should face the maintenance access point.

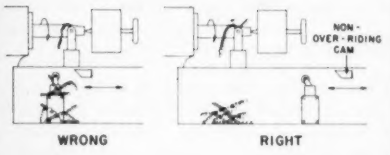


Limit switches should not be submerged in or splashed with oils, coolants, or other liquids unless specifically designed for such service.

TABLE IV continued



Limit switches should be placed in locations where machining chips do not accumulate under normal operating conditions.



Limit switches should not be used in locations where temperature or atmospheric conditions are beyond those for which they have been specifically designed.

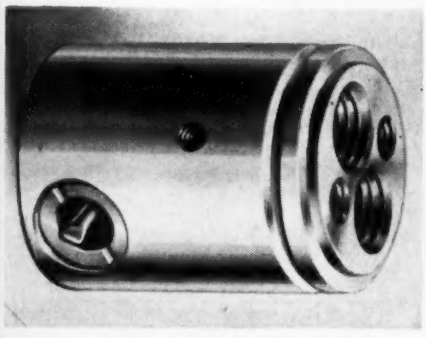


Fig. 18—Ball-type inertia switch.

TABLE V

PRESSURE SWITCH TERMINOLOGY

ACTUATION POINT	*The pressure at which the electrical switch is actuated.*
DEACTUATION POINT	*The pressure at which the electrical switch is returned to its original condition.*
ACCURACY	*The ability of a pressure switch to repeat its operation consistently.*
TOLERANCE	*The operational limits of a pressure switch, under all specified operating and environmental conditions.*
ADJUSTMENT RANGE	*The pressure limits within which both the actuation point and the deactuation point may be adjusted.*
DIFFERENTIAL VALUE	*The pressure difference between actuation point and deactuation point.*
ACTUATOR OR SENSOR	*The diaphragm, capsule bellows, piston, Bourdon tube, etc. that senses the pressure and actuates the circuit changing mechanism.*
KINDS OF PRESSURE	
ABSOLUTE:	*The difference between perfect vacuum, or zero pressure absolute and known pressure. It is the sum of gauge pressure and barometric pressure.*
AMBIENT:	*The exterior pressure surrounding the pressure switch. It may or may not be atmospheric pressure.*
ATMOSPHERIC OR BAROMETRIC:	*Standard barometer reading at sea level and 32°F is 29.92 inches of mercury. This pressure decreases, but not uniformly, with altitude.*
DIFFERENTIAL:	*The difference between a variable pressure and a reference pressure, or between two variable pressures.*
GAUGE:	*The pressure indicated by a common pressure gauge above (or below) atmospheric pressure, and varying with barometer reading.*
PROOF:	*The safe pressure level that can be applied without permanently changing the actuation point.*
RATIO:	*The ratio between two pressures. Actuation point of a ratio switch is based on the ratio of two pressures.*
REFERENCE:	*A specified pressure on which actuation point is based; may be absolute, or controlled pressure.*
STATIC:	*The pressure maintained by a head of stationary fluid.*
VARIABLE:	*A changing pressure, normally the one which actuates the pressure switch.*
WORKING PRESSURE:	*The pressure of the system in which the pressure switch is used.*

been developed. There are some companies whose output depends almost entirely on some specialized design which they have brought to an advanced point of development. In this section, we will briefly consider some of the more specialized switches.

Inertia Switch, Inc. has developed a new acceleration switch, for applications involving critical control or limits on acceleration changes in two directions. Used in missiles and aircraft, this switch, Fig. 18, is responsive to axial acceleration, uni- and bi-directionally, from 5g to 50g. Its actuating time is 20 millisecs, with accuracy within 5%.

A new design is responsible for the accuracy, dependability and repeatability. It has only one moving part: a precision ground ball held by a uniform magnetic field. The ball is released to close or open an electric circuit when the force of acceleration exceeds the magnetic force.

The switch is factory pre-set, with nominal setting specified by the user. It can be adjusted if desired. Its service life is 100,000 cycles, and it meets MIL-E-5272-A.

Electro-Tec describes a low torque, miniature rotary selector switch of novel and useful character. In the design of the switch, housed in a size-10 synchro housing, each input ring is interconnected to a separate segment of the commutator ring (output). Every other segment of the commutator is "dead", yielding a "break-before-make" switching arrangement. With this switching sequence, up to 12 circuits and more can be incorporated. Additional circuitry can be obtained by increasing the housing size.

Fig. 19 shows Electro-Tec's standard 8 position switch. The variations on this standard switch are innumerable. For example, by merely eliminating the dead segments, a "make-before-break" switch is obtained. By adding two or more commutator rings, and by interconnecting the input rings to require segments of the commutator ring or rings, wide variations in output signals are obtained. The interconnection between rings is done internally, i.e., all wires are buried in the plastic material which makes up the rotor. Separate circuits can also be built into the switch, so that two or more operations can be done by a single switch.

These Electro-Tec switches described

are designed for low current and voltage applications, such as, sampling, selecting, telemetering, wave-shaping, counting, computor conversion, etc.

A field where rotary switches are finding new applications is in scheduling and programming devices. Here, switches are replacing transistor circuits with a considerable saving in cost and weight and with a great increase in reliability. To increase the current switching capacity for these applications, silver graphite brushes may be used.

Electrolytic switches have been described by Lear. A specific type was originally designed as a leveling switch to control the torque motors in a gyro stabilizing system. These alternating-current units may be applied as highly-sensitive leveling devices, (see Fig. 20).

In the Lear design, the switch body is of glass, fused to an alloy cup of 5% iridium, 95% platinum. The receptacle is partially filled with a special electrolyte, in precisely-controlled quantity, to leave an air bubble of exact dimensions. When the switch is tilted from true horizontal, the bubble shifts position, varying the amount of electrolyte in contact with the iridium-platinum electrodes. The resultant change in conductivity and variation in current may be used to control electrical circuits to assure a true gravity-referenced position on both axes at all times. Fig. 21 shows the performance of this switch as a function of angular displacement and temperature.

Recently Ovitron has announced an electrically controlled electrolytic switch

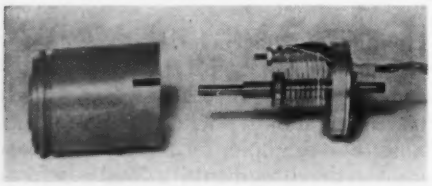


Fig. 19—Standard 8 position rotary selector switch made by Electro-Tec.

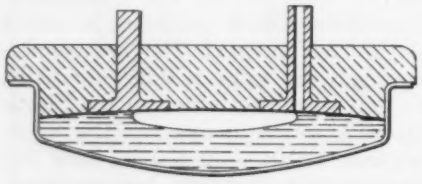


Fig. 20—Configuration of Lear electrolyte switch.

TABLE VI

SELECTION AND FITTING OF MERCURY SWITCHES

TYPE OF GLASS

1. Plain glass, primarily used in auxiliary or control circuits as open-circuit, load or load-reversal switch or as occasionally used motor switch.

2 Plain glass with liner in the form of a ceramic insert, used in normal type of load, load reversal and motor circuits.

3. Hard glass without liner used as frequently-operated load and load reversal switch where increased safety is demanded. This glass is recommended for all special-purpose types especially in cases where the actual switching is controlled by the shape of the glass body as in time-lag switches.

4. Hard glass with liner made of porcelain fused on to the body. For very frequent switch operation, used in motor, make, break, load, load reversal circuits.

5. Hard glass with quartz liner, a material with an extremely high resistance to arcing. Is normally used when exceptionally high reliability and a long service life is required.

THE USEFUL SERVICE LIFE OF A MERCURY SWITCH DEPENDS ON:

1. The rated electrical values of the current circuit and the operating conditions.

2. The mechanical characteristics of the unit motivating the switch.

3. The effect of the operating energy produced by this motive unit on the mercury switch.

4. The shape and type of the fitting used to hold the switch.

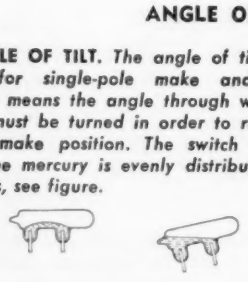
The following should be noted in respect to 2 and 4: (a) Low and uniform tilt speeds. (b) The switch should not be brought to a sharp stop at the make or the break position. (c) Shock-resisting spacers between switch and its fitting.

When planning the layout of a circuit, provision should be made for the incorporation of series-connected fuses, line or motor protective switches to take care of any possible short circuit.

TABLE VII

ANGLE OF TILT DESIGNATIONS

1. ANGLE OF TILT. *The angle of tilt figure given for single-pole make and break switches means the angle through which the switch must be turned in order to reach the on or make position. The switch is "on" when the mercury is evenly distributed over the cups, see figure.*



Correct (a) and incorrect (b) positions used in defining tilt angle.

This point is of particular importance when the same amount of movement takes place every time the switch is moved to "off".

Ring or metal electrode switches are considered as being on when the electrodes are submerged about .02" into the mercury.

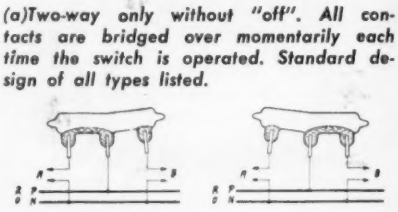
2. TILT ANGLE ON REVERSING SWITCHES. *The angle of tilt quoted for reversing switches is the angle through which the switch must pass to move from operational position A to operational position B. When a plus-minus angle is quoted this signifies that the mercury switch must be turned through minus x degrees to the left and through plus x degrees to the right.*

3. OVERSWITCHING TILT ANGLE. *Quite often it is necessary to quote the so-called overswitching tilt angle of make, break or reversing switches. This is the angle through which the switch can be turned and still remain "on".*

For example: Angle of tilt 5 degrees, overswitching tilt angle 20 degrees. The switch will remain switched "on" in a range of 20 minus 5 degrees i.e. 15 degrees. After the switch passes out of this range it will switch off.

4. THE FOLLOWING COMMON TYPES OF MAKE AND BREAK SWITCHES ARE AVAILABLE.

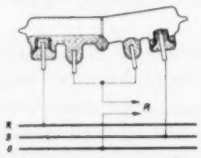
(a)Two-way only without "off". All contacts are bridged over momentarily each time the switch is operated. Standard design of all types listed.



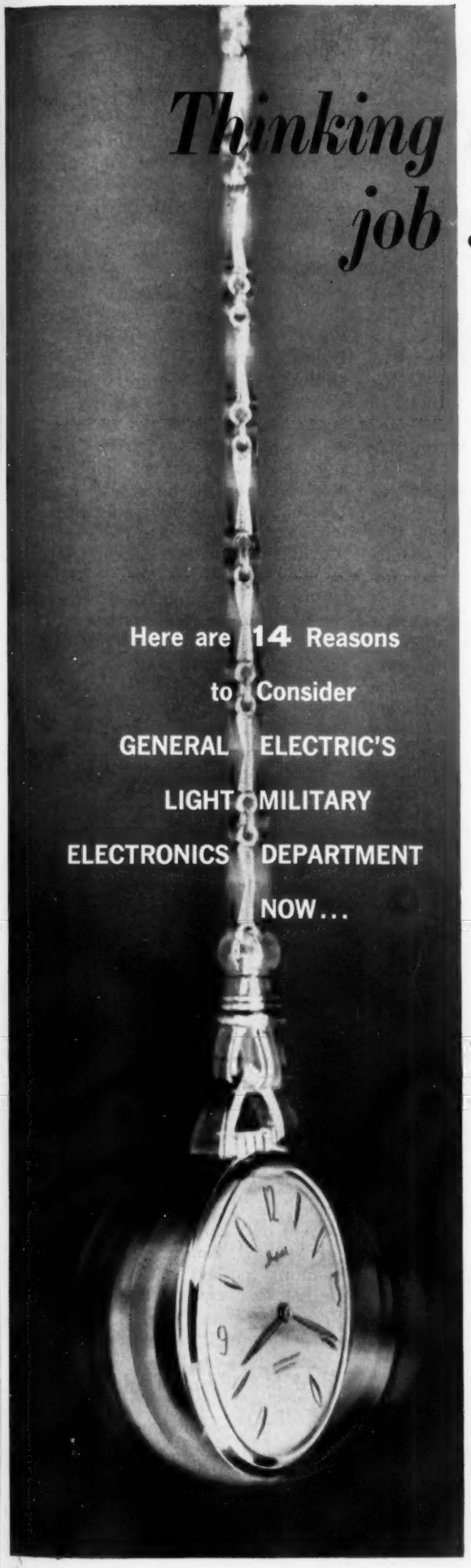
(b)Two-way and paralleling switches. All three contacts are bridged with mercury when switch is in the centre position.

(c)Two-way and off switch. With the switch in the centre position all the contacts are isolated. When the switch is moved rapidly there is a distinct possibility that all three contacts will be momentarily bridged.

(d)Suitable fuse security must be provided for those reversing switches i.e. phase selection or motor reversal, where two potentials are direct coupled to the switch.



Example of phase selection.



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for industrial applications. This switch, properly applied, is claimed to have indefinite switching life. Power handling capacities are given in hundreds of watts.

Haydon Switch originally developed hermetically sealed subminiature switches to meet the rugged environmental conditions of military applications. As general industrial requirements have become increasingly more demanding, many manufacturers have been willing to pay more for a *sealed* switch as a guarantee of foolproof operation. In particular, higher temperatures and use of dry circuits have created the need for contacts that remain completely uncontaminated over a long period of time. Haydon accomplishes this by evacuating the switch and filling it with an inert gas before final hermetic sealing. These Haydon switches are qualified to the basic snap-action switch specification, MIL-S-6743, and to the vibration requirements of MIL-E-5272A, Procedure II (20-2000 CPS at 20 G's).

Revere Corp. of America in Wallingford, Conn. manufactures a unique magnetically actuated, dry-read Glaswitch of the single pole, single throw —normally open—snap action type. Contacts are actuated by an external magnetic field, which may be obtained from a permanent magnet, electromagnet or combination of both. The contacts may be magnetically biased to a normally closed position and magnetically actuated to the open position. Hermetically sealed *in an* atmosphere of *dry nitrogen* with a helium tracer, the unit has an operating time of 1 millisecond, operating rate of up to 400 cycles per second, long life and temperature range from —320 to +300F standard or —350 to 500F special.

Acro Div. of Robertshaw-Fulton manufactures a dust and oil tight switch that can control up to four separate circuits for either pilot or line duty in machine tool applications. The actuator is adjustable 360° in two planes and the rolling spring switch is readily replaceable. It is available in two types: double action for controlling the switch contacts when the actuator is moved either side of center or "at rest" position and single action for operating the switch contacts only when the actuator is moved in one direction from the "at rest" position.

Break-glass switches by Automatic Switch Co. are used as emergency safety controls.

Esco manufactures a heavy-duty momentary - contact (spring - return) switch encased in a rugged pistol-grip handle and installed at the end of a rubber-covered 4-conductor cable.

Thermo Electric Co. manufactures key or push-button cabinet type switches where a large number of thermocouples or resistance bulbs must be checked frequently.

Hetherington, Inc. announces a miniature SPST toggle switch with a silicone rubber cap on the toggle for added protection against moisture.

Joy announces weathertight, completely sealed portable push-button stations.

Time delay switches providing screw-type adjustable delays (from 3-40 seconds) are described by Controls Co. of America. This company also manufactures a pressure sensitive switch for liquid level measurement.

Gertsch features a subminiature coaxial switch unit, meeting MIL specs, and designed for remote electrical control of decade or binary information. Within the unit are 3 or 4 sub-miniature switches with up to 10 positions on each switch controlled by the concentric dial arrangement. Connection to these switches are made by means of a sub-miniature connector at the rear.

Precision Mechanisms Corp. manufactures a limit switch-stop for instrument and servomechanism applications. The range adjustment screw permits rapid adjustment to any angular rotation from zero to twenty-five turns. Limit switches are actuated at either end of shaft travel just prior to contact with non-locking limiting stops.

MERCURY SWITCHES

Mercury switches offer an important field of potential applications because of their capability of making or breaking electric circuits using a liquid conductor. The important performance features are:

- Low operational energy required since energy isn't needed to actuate the contacts.
- Environment cannot cause damage to points of contact.
- Practically constant contact resistance even with low voltages.
- Good contact at all times even when switched on permanently and without special maintenance.
- No possibility of igniting combustible gases by the switching arc.
- Instantaneous make or break due to the surface voltage of the mercury so that these switches are ideal as thermal make and break switches or for use with regulators of a similar nature.
- The glass body can be shaped to almost any form. Fitted with suitable baffles, such switches are ideal for use with all types of time switches.
- Possibilities of fitting or installing into the widest variety of designs.
- No contact "chatter" when switch is closed.

In Table VI, Willy Günther K.G. provides hints on selection and fitting of mercury switches, and in Table VII they suggest angle of tilt designation. *PROTECTED MERCURY SWITCHES.* Protected switches are designed for applications that require resistance to severe shock and impact as well as foreign elements. Protected switches may consist of ordinary high quality glass tube mercury switches embedded in solid wax or plastic inside metal or phenolic cases. The embedment material not only protects the switch but provides seal and electrical insulation around the lead entrance. The enclosure also simplifies mounting since the unit can be rigidly screw-mounted to moving parts or pivoted on pins for tilt operation. There are no spaces inside the enclosure where moisture can collect to cause corrosion or electrical failure.

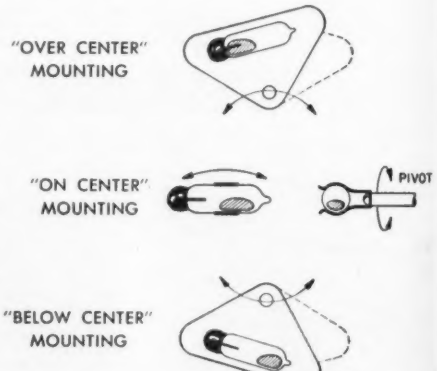

Fig. 21—Methods of mounting mercury switches as illustrated by Micro Switch.

MOUNTING. In mounting mercury switches, Minneapolis Honeywell describes three general mounting methods (1) over center, (2) on center and (3) below center. The preferred mounting method is over center. See Fig. 21.

(1) "Over center" mounting helps improve the quick contact action of the mercury. If a small free motion is designed in the support mechanism an extra "over center" snap-action can occur as the mercury over-balances the device, picking up this free motion.

(2) In applications where minimum operating space is a requirement, "on center" mounting results in a minimum of displacement of each end of the tube. In this mounting method a minimum of material is needed to support

the switch tube. Often the mounting clip can be combined with the pivot. (3) In applications where only minimum operating force is available "below center" mounting is suggested. Lowest operating force can be secured by counterbalancing the switch and its support. The mercury is not lifted any appreciable distance. The actuating mechanism and switch tube move while the mercury almost stands still.

ZERO ADJUSTMENT. In any mounting the need for "zero adjustment" (setting the switch operating position with respect to equipment to be controlled) should be reviewed. In very exacting applications a small pendulum or plumb bar designed into the device often helps to insure accurate positioning during installation.

MOUNTING CLIPS. Mounting clips are designed to hold the switch securely. Tube movement incident to slipping and tampering can be avoided by running a wire through the holes in the mounting clip, then twisting the wires to lock them. Cement should be applied to secure the wire and clip to the tube. Mounting clips by Micro Switch Div. of Minneapolis-Honeywell are shown in Fig. 22.

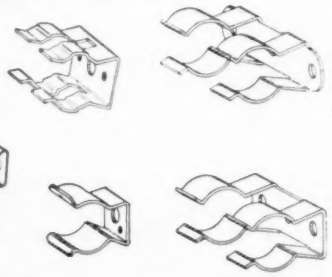

Fig. 22—Mounting clips made by Micro Switch.

CROSSBAR SWITCHES

The development of compact, fast acting and reliable crossbar switches has simplified the performance of many functions hitherto achievable only by complex arrays of equipment.

In general form, a crossbar switch, such as shown in Fig. 23, is a 3 dimensional arrangement of electrical contacts individually operated by the appropriate selection of the coordinates of the contact. Fig. 24 is a diagram of a crosspoint in a Cunningham crossbar switch showing how a coordinate magnet system operates the switching matrix. Table VIII lists some of the modes of operation. In practical designs, there are limits to the number and sequence of contact operations. However, uses of the switch are readily visualized, in spite of these limits.

Brief reflection will indicate the great flexibility of this type of device. Consider the operation of scanning, in

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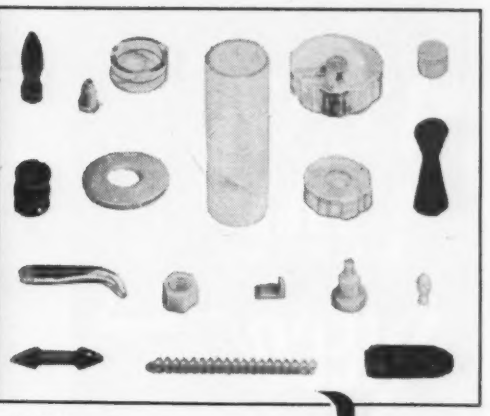

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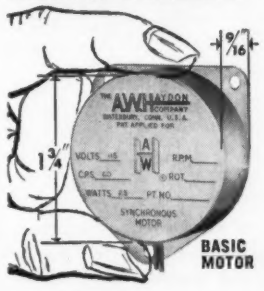

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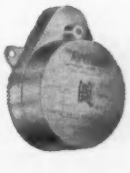

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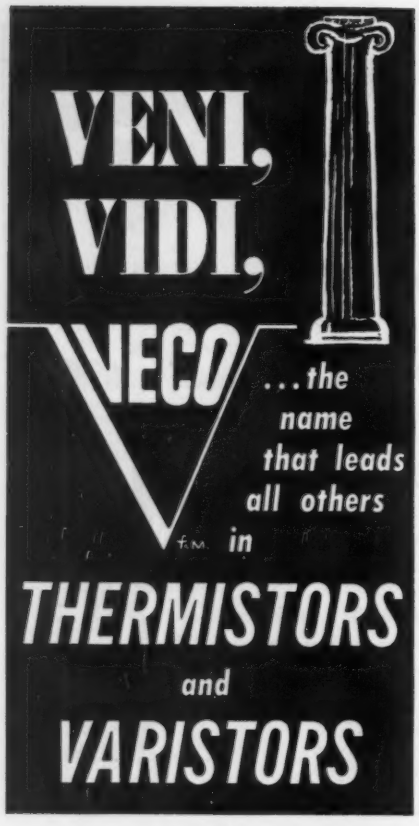

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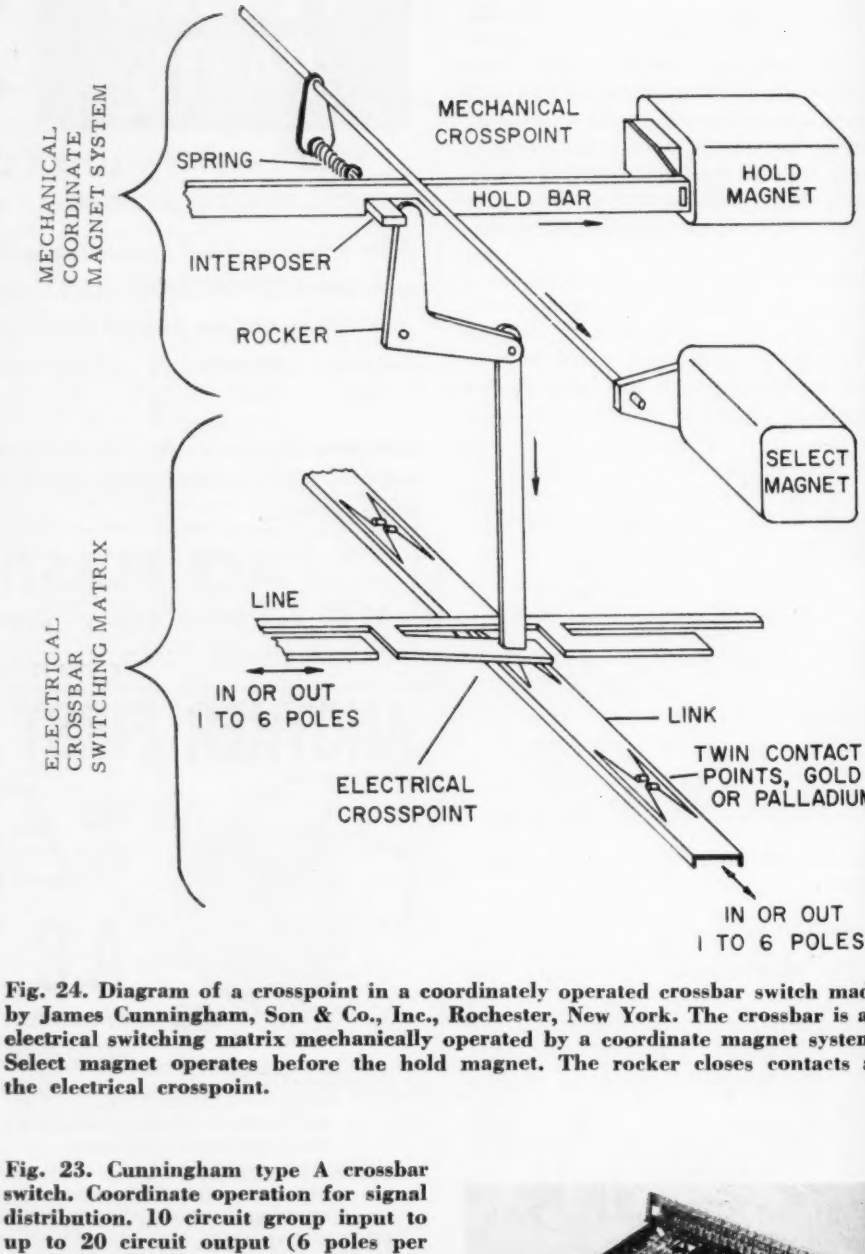


Fig. 24. Diagram of a crosspoint in a coordinately operated crossbar switch made by James Cunningham, Son & Co., Inc., Rochester, New York. The crossbar is an electrical switching matrix mechanically operated by a coordinate magnet system. Select magnet operates before the hold magnet. The rocker closes contacts at the electrical crosspoint.

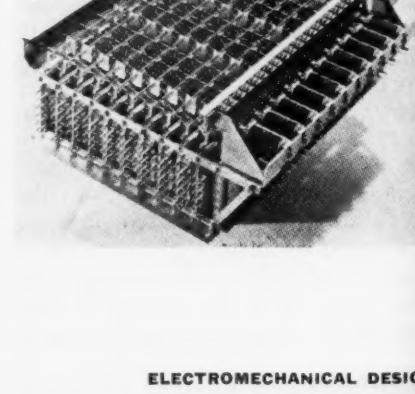


Fig. 23. Cunningham type A crossbar switch. Coordinate operation for signal distribution. 10 circuit group input to up to 20 circuit output (6 poles per circuit).

Function and operation: Group to Group switching. **By means of a coordinate system of select and hold magnets operated sequentially, a mechanical operation is performed at a crosspoint. This mechanical operation in turn makes electrical connection at the crosspoint, closing a circuit between one input and one output. In sequence, by similar operation the balance of the inputs are connected to outputs in any combination.**

TABLE VIII

MODES OF OPERATING AND CONTROLLING SWITCHES

1. *Pushbutton*—Pushbuttons arranged coordinately with the hold and select magnets is the simplest form of control and random selection of any of the crosspoints. The buttons can operate the selected crosspoints directly.

2. *Dial*—For most remote control applications, the dial provides considerable saving of space and wiring and can also give scanning as well as random selection instructions to switch with only two wires. Multiple control can be easily set up.

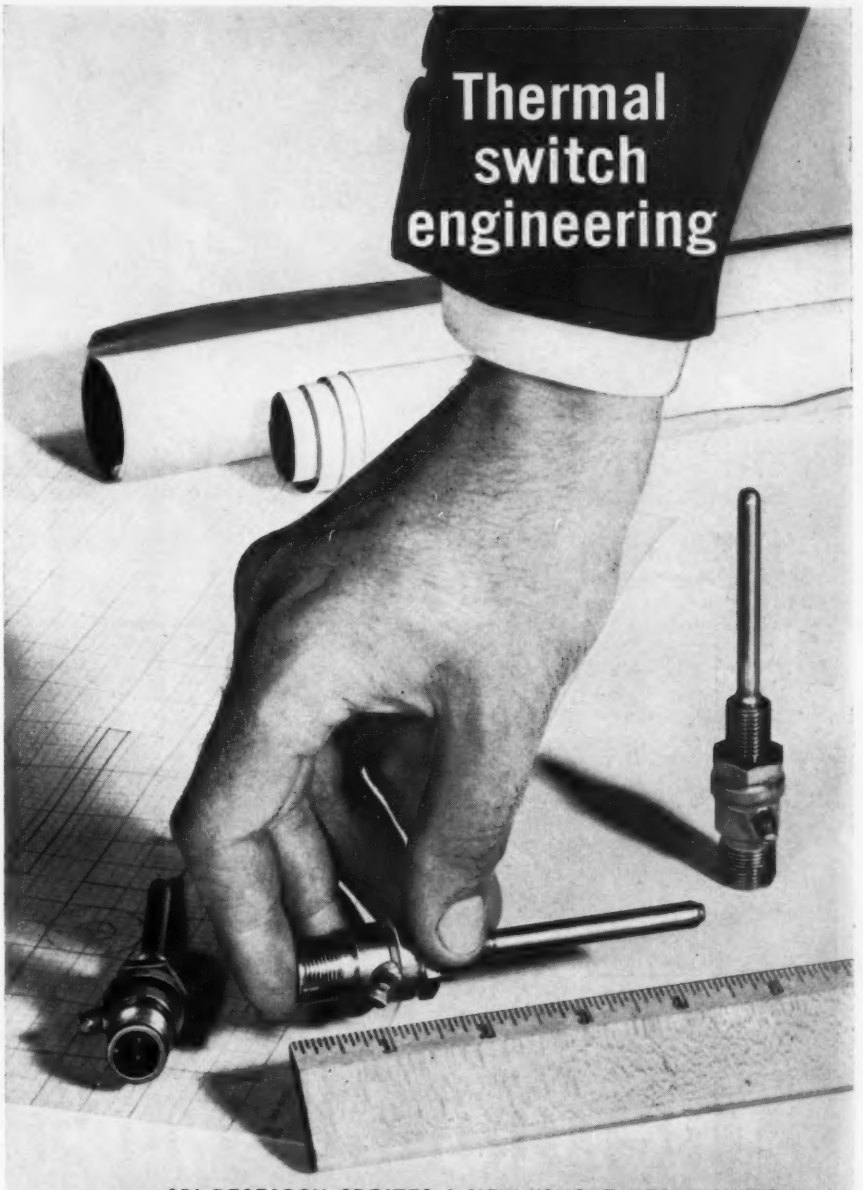
3. *Punched Card or Tape*—Conventional binary (with decoder) or digital coded cards or tape can be used to select or scan switch. The addition of a simple high speed electronic multiplexer permits the switch to scan at high rates of speed.

4. *Self-Stepping*—Using off-normal or control contacts associated with the hold and select magnets, the switch will step itself. The speed or scan program can be regulated by external command pulses.

sequence, a number of circuits corresponding to the capacity of the switch. Used in conjunction with stepper switches which provide scanning control, the switch contacts may be closed sequentially from the first to the last contact in response to control pulses. Much more complex switching sequences are possible when the switch is operated from punched cards, tape or computer output.

A simple digital to analog converter can be achieved by combining a crossbar switch with sets of precision resistors arranged to form several banks of voltage dividers. Closing of contacts in accordance with a digital input provides an accurate voltage division ratio from which an analog output is easily derived. Similarly an analog-digital converter may be devised, based upon comparing the output of a resistance voltage divider circuit associated with the crossbar switch with the unknown voltage to be digitized.

The basic advantage of the crossbar switch is its flexibility in handling a great many circuits in a compact mechanical package. The variety of control modes permits a striking simplification in digital circuitry where much of the logic required is provided by the crossbar. The crossbar can replace a great deal of wiring and individual components. The quality of the electrical contacts, and the freedom from cross-talk are suitable for practically all applications, including low-level

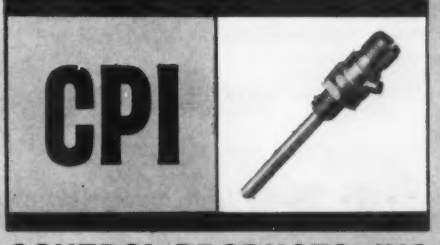


CPI RESEARCH CREATES A NEW "SHORT HEAD" SWITCH

From CPI research comes this new thermal switch with the shortest head construction of any AN connector type switch. This hermetically sealed, field adjustable, probe type switch was developed for an aircraft manufacturer to control inlet air temperature for heating and turbine exhaust temperatures for air conditioners.

There are other uses, too—controlling temperatures of gas turbines and heat exchangers or oil in gear boxes—in fact, many places where there's need for a hermetically sealed switch with a fast, easy electrical connection. It is possible that this or the many others developed by CPI specialists may not solve your problem. If not, CPI research can create the switch that will! Send your specs.

This new switch is constructed of all high temperature alloys and has a calibration range of —20F to 1750F with safe momentary overshoot to 2000F and undershoot to —100F. It is available in a variety of threaded and plate mountings. Mention "Spec-Stat" when inquiring.



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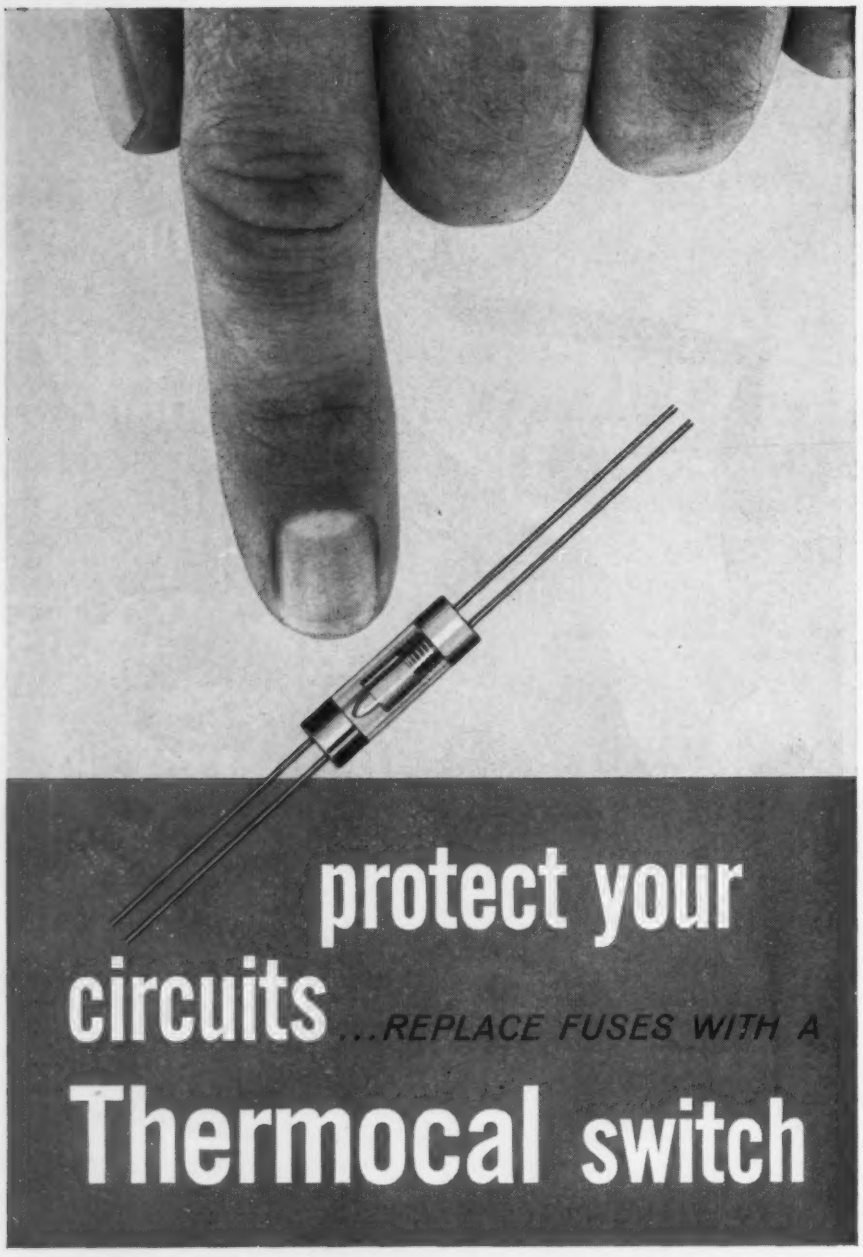

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Regarding life, that everpresent problem in contactor devices, the Cunningham crossbar is rated at 20,000,000 operations minimum *per crosspoint* at 1/10 ampere non-inductive at 50 volts d-c. This current rating is sufficiently high (5 watts) to drive many types of output devices directly, without the need for interposing buffer amplifiers. Contact bounce is restricted to 200 microseconds on make.

On the negative side, since the switch is mechanical, its speed of operation is necessarily limited. On the Cunningham crossbar, "hold coils" with magnetic inductance require 6-7 milliseconds for actuation although this time can be cut in half by operation from a high impedance current source. When the switch is appropriately driven, its operation is restricted to less than 100 points-second, which is of the order of high speed, relay-type devices.

The following information is suggested in specifying a cross-bar switch for scanning purposes:

- Number of positions to be scanned
- Number of wires (poles) per position
- Minimum and maximum speeds of scan in positions per second
- Modes of control: 1) Dial 2) Push-button 3) Self pulse 4) External pulse
- Signal characteristics
- Special mounting requirements
- Life requirements
- Specify whether contact is bridging or non-bridging.

Ball Ways Minimize Stixion

Beaver ball way cartridges are now being employed to virtually eliminate breakaway friction on horizontal sliding tables and other machine tool parts. While ball and roller type ways have been used in the past to contend with stixion, they have generally been of the rolling "caged" type which must be 50% longer than the table to provide support for extreme positioning on the bed. The new cartridges are attached to and made a part of the moving unit. Balls are recirculated within the cartridge as they are recirculated within the nut of ball screws.

Beaver Precision Products, Inc., Clawson, Mich.

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